# Washington Department of Fish and Wildlife's Priority Habitat and Species Management Recommendations Volume IV: Birds

## Shorebirds: Plovers, Oystercatchers, Avocets and Stilts, Sandpipers, Snipes, and Phalaropes

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## GENERAL RANGE AND WASHINGTON DISTRIBUTION

Shorebirds are represented in Washington by many families, including plovers, oystercatchers, avocets and stilts, sandpipers, snipes, and phalaropes (Paulson 1993). In Washington, shorebirds occur as year-round residents, breeding or summer residents, spring and/or fall migrants, and migrants that winter in the region (Table 1). Some species, such as the killdeer and spotted sandpiper, have resident and migrant sub-populations.

The vast majority of wintering and migratory shorebirds in Washington occur at coastal estuaries (Figure 1). These areas include the Columbia River estuary, Willapa Bay, Grays Harbor, coastal Washington beaches, the Strait of Juan de Fuca, Hood Canal, the San Juan Islands, and the Greater Puget Sound region (Figure 1). The highest counts of wintering birds are from Willapa Bay (38,000-90,000 shorebirds; Buchanan and Evenson 1997), Grays Harbor (approximately 20,000 shorebirds annually during 1979- 1988; Paulson 1993, Brennan et al. 1985), and the northern estuaries of Puget Sound (>10,000 shorebirds at several estuaries and >50,000 shorebirds in the region; Evenson and Buchanan 1995, 1997).

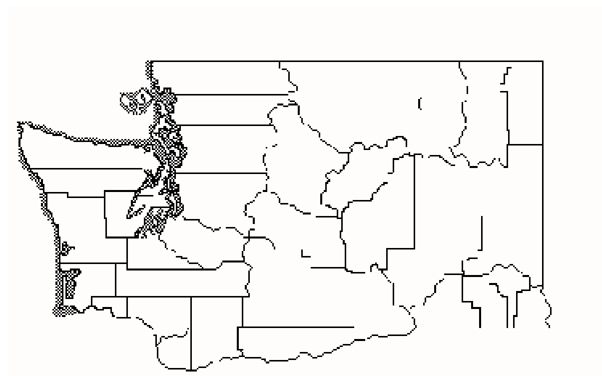

Figure 1: Primary wintering and migratory ranges of shorebirds associated with estuaries and/or shoreline habitats in Washington. Various shorebird species are also associated with fresh water or other upland habitats which are difficult to generalize and identify on a map of this scale (see text). Map derived from the literature.

The most significant areas during migration include Grays Harbor (>one million shorebirds during spring; Herman and Bulger 1981), Willapa Bay (>100,000 shorebirds during spring; Buchanan and Evenson 1997), and the many estuaries of Puget Sound (>50,000 shorebirds during spring; Evenson and Buchanan 1997). Species such as the red-necked phalarope may occur in large numbers offshore during migration (Jehl 1986). Other significant wintering and migratory staging areas in the region include Boundary Bay and the Fraser River delta in southern coastal British Columbia, Canada (Butler and Campbell 1987, Butler 1994, Vermeer et al. 1994).

Other habitats in western Washington are also important for shorebirds. Flocks of black-bellied plovers and dunlins occasionally occur at non-estuarine sites in western Washington (e.g., flooded fields in the Wynoochee and Chehalis River valleys) during migration or winter periods (J. Buchanan, unpublished data). Some of these birds may have been temporarily displaced by flooding (Strauch 1966) or other conditions that reduced prey availability at coastal estuaries (Townshend 1981). Large numbers of shorebirds forage and roost on ocean beaches during winter (Buchanan 1992) and migration (Myers 1988-89, Myers et al. 1986). Other important habitats include rocky shorelines and the pelagic zones (Paulson 1993).

Compared to the coastal region, shorebirds are far less abundant at wintering and migratory stop-over areas in the eastern part of the state where they occur at widely scattered ponds, "potholes" and lakes, marshes, flooded fields, and riverine systems (Paulson 1993). As is true in other interior regions in North America, the seasonal distribution and abundance of shorebirds in this part of the state is somewhat unpredictable in that the suitability of shorebird habitats in many areas is dependent on changing water levels that are sensitive to varying water use practices, drought, and other environmental conditions (Fredrickson and Reid 1990, Skagen 1997). The highest counts of migratory shorebirds (most counts are <1,000 birds) in the interior region of Washington are from Lake Lenore (i.e., red-necked phalarope), Soap Lake, Turnbull National Wildlife Refuge, Yakima River delta, and water bodies near Reardan (Paulson 1993). It is likely that other areas of concentrated use by shorebirds have not been documented. In Washington, the primary breeding ranges of the American avocet, black-necked stilt, and Wilson’s phalarope occur within the Columbia Plateau region in the eastern part of the state.

## Breeding and Wintering Ranges

The breeding distribution of migrant shorebirds includes species that nest locally, such as the spotted sandpiper and American avocet (Jewett et al. 1953), and also species that nest in the arctic and subarctic, such as the dunlin and western sandpiper. The wintering range of nearctic shorebirds is vast, extending from southeastern Alaska to southern South America (Morrison 1984) and generally falls within 3 categories: 1) wintering areas primarily within North America, 2) wintering areas extending throughout much of the western hemisphere, and 3) wintering areas primarily within South America.

## Distribution of Age and Sex Classes

The age and sex compositions of some shorebird populations vary spatially and temporally across their ranges. Examples of local or regional spatial segregation can be found, although the population structure of most species is poorly known. For example, adult male and juvenile western sandpipers winter primarily in western North America whereas most females of this species winter in South America (Page et al. 1972). Additionally, populations of wintering dunlins exhibit pronounced local and regional segregation by age class (Kus et al. 1984, van der Have and Nieboer 1984, Buchanan et al. 1986).

Temporal segregation of age and sex classes occurs during migration in many species (Morrison 1984, Butler et al. 1987). In Washington, this segregation involves 2 of the most abundant species in western North America, the western sandpiper and dunlin (Page and Gill 1994). An understanding of spatial and temporal segregation can be important for population and habitat management, because habitat loss or degradation at certain wintering or migratory staging areas may significantly impact specific age or sex classes of these or other species at the local, regional, or population level.

## RATIONALE

Over 40 species of shorebirds occur in Washington throughout their breeding and nonbreeding seasons (Paulson 1993, Gill et al. 1994). Two of these, the snowy plover (*Charadrius alexandrinus*) and the upland sandpiper (*Bartramia longicauda*), are listed as State Endangered species (the upland sandpiper may be approaching extirpation in Washington). During the nonbreeding period, most shorebird species in Washington aggregate in large single- or multi-species flocks at estuaries, beaches, wetlands, or other foraging and/or roosting locations. Because of the limited distribution of these habitats, and the propensity of shorebirds to form large aggregations, shorebirds are vulnerable to habitat loss; chemical, metal or oil pollution; various disturbance factors; and other potentially significant impacts.

Many shorebird species are long-distance migrants that travel thousands of miles between wintering and breeding areas. The availability of wintering sites and migratory staging areas has decreased throughout North America due to the destruction of biologically rich but economically important areas used by these birds (Page and Gill 1994, Skagen 1997). The number and quality of these sites likely constrains shorebird populations during the nonbreeding season (Myers 1983, Senner and Howe 1984, Myers et al. 1987b), although habitat loss can adversely impact shorebird populations at any season (Evans and Pienkowski 1984, Goss-Custard and Durell 1990, Sutherland and Goss-Custard 1991).

Nearly all of Washington's shorebird species are represented by individual birds en route to wintering grounds in Central or South America or breeding grounds in Alaska, Canada or the Russian Far East. A number of sites in Washington support substantial shorebird populations (Herman and Bulger 1981, Evenson and Buchanan 1995, Buchanan and Evenson 1997) and qualify as important regional or hemispheric sites in the Western Hemisphere Shorebird Reserve Network (Myers et al. 1987a). Moreover, the region as a whole supports huge numbers of birds during winter and migration. Consequently, during one season or another, this region supports substantial segments of shorebird populations that are truly international in their distribution (Gratto-Trevor and Dickson 1994). For this reason, shorebird populations and the habitats they use in Washington are integral components of a greater hemispherical population of birds and must be managed from this international perspective (Gill et al. 1994).

Large-scale censuses of shorebirds conducted in Britain (Prater 1981, Moser 1987), the Canadian Arctic (Gratto-Trevor et al. 1998), and eastern North America (Howe et al. 1989, Morrison et al. 1994a) indicate that populations of many species are declining. Long-term research from migratory staging areas in eastern North America indicates that several species of shorebirds, including some that also migrate through Washington, have experienced significant population declines along the east coast (scientific names are presented in Table 1): black-bellied plover, semipalmated plover, whimbrel, ruddy turnstone, red knot, sanderling, semipalmated sandpiper, least sandpiper, and short-billed dowitcher (Howe et al. 1989, Morrison et al. 1994a). Populations of American golden-plover, lesser yellowlegs, red-necked phalarope, and red phalarope are also thought to have declined in Canadian breeding areas (Haig et al. 1997, Sauer et al. 1997, Gratto-Trevor et al. 1998).

Other species have experienced population declines as well. For example, the size of the wintering population of rock sandpipers along the Pacific coast of Oregon, Washington, and British Columbia declined suddenly and dramatically (and appears to have shifted north to Alaska) in association with the 1982-83 El Niño event (Buchanan in review). Black turnstone numbers have also declined along the Pacific Northwest coast (Paulson 1993). Species such as the snowy plover and upland sandpiper have also clearly declined in response to habitat destruction (Washington Department of Fish and Wildlife 1995a, 1995b). Analyses of data collected from Breeding Bird Survey routes throughout Washington indicate the occurrence of significant population declines at one or more spatial or temporal scales for the following four species of locally-nesting shorebirds: spotted sandpiper in the Columbia Basin, (-9.1% between 1966 and 1996), killdeer statewide (-2.3% between 1966 and 1996 and -4.1% between 1980 and 1996), common snipe in the Columbia Basin (-3.2% between 1966 and 1996) and statewide (-5.5% between 1980 and 1996), and Wilson's phalarope in the Columbia Basin (-10.9% between 1980 and 1996) (Sauer et al. 1997).

Table 1. Seasonal abundance and habitat use of shorebirds in Washington. Habitats are described in Paulson (1992, 1993). Bold text refers to primary habitat or area where the species is locally or seasonally common; standard text refers to secondary habitats. Abundance codes are from (Paulson 1993). Seasonal abundance codes may differ from Paulson (1993) based on other available information. Codes with an asterisk (*) represent unique local populations. Abundance codes in parentheses refer to interior Washington.

| Species | Abundance by season[a] | | | | Habitat |
|---|---|---|---|---|---|
| | Winter | Spring | Summer | Fall | |
| Black-bellied plover (*Pluvialis squatarola*) | VA | VA (VU) | FC | VA (U) | **coastal and estuarine sand beaches and mud flats,** exposed shorelines of ponds and lakes, **farmland,** wet lowland meadow |
| American golden-plover (*Pluvialis dominica*) | | R | | C (U) | **coastal and estuarine mud flats and saltmarsh,** exposed shorelines of ponds and lakes, farmland, alpine/subalpine meadow, wet lowland meadow |
| Pacific golden-plover (*Pluvialis fulva*) | VR | R | | C | **coastal and estuarine mud flats and saltmarsh,** exposed shorelines of ponds and lakes, farmland, alpine/subalpine meadow, wet lowland meadow |
| Snowy plover (*Charadrius alexandrinus*) | U | FC* | FC* | FC* | **coastal sand beaches** |
| Semipalmated plover (*Charadrius semipalmatus*) | FC | A (VU) | U | A (U) | **coastal and estuarine sand beaches and mud flats, exposed shorelines of ponds and lakes** |

| Species | Abundance by season[a] | | | | Habitat |
|---|---|---|---|---|---|
| | Winter | Spring | Summer | Fall | |
| Killdeer (*Charadrius vociferus*) | C (U) | C (C) | C (C) | C (C) | estuarine mud flats and **saltmarsh; exposed shores of ponds, lakes,** and large rivers; **fresh marsh, wet lowland meadow, grassy areas and farmland** |
| Black Oystercatcher (*Haematopus bachmani*) | FC | FC | FC | FC | **coastal rocky shore** |
| Black-necked stilt (*Himantopus mexicanus*) | | VU (U) | (FC) | | **shallow marshy ponds and lakes** |
| American avocet (*Recurvirostra americana*) | | R (FC) | (C) | R (A) | **shallow marshy ponds and lakes** |
| Greater yellowlegs (*Tringa melanoleuca*) | VC (VU) | VC (FC) | R | VC (FC) | **estuarine mud flats**, **shorelines of shallow ponds, lakes and large rivers,** flooded fields |
| Lesser yellowlegs (*Tringa flavipes*) | | VU (U) | | FC (FC) | estuarine mud flats, **shorelines of shallow ponds and lakes,** flooded fields, |
| Solitary sandpiper (*Tringa solitaria*) | | U (VU) | (R) | VU (U) | **shorelines of shallow ponds and lakes, including those found in wooded settings; flooded fields and other ephemeral freshwater areas** |
| Willet (*Catoptrophorus semipalmatus*) | U* | VU (VU) | (U) | VU (VU) | shorelines of shallow ponds and lakes, **estuarine mud flats** |
| Wandering tattler (*Heteroscelus incanus*) | | FC | | FC | **coastal rocky shores** |

| Species | Abundance by season[a] | | | | Habitat |
| --- | --- | --- | --- | --- | --- |
| | Winter | Spring | Summer | Fall | |
| Spotted sandpiper (*Actitis macularia*) | U* | U (U) | U (R) | U (VU) | **shorelines of streams, rivers, shallow ponds and lakes, marshes;** rocky shore, estuarine mud flats |
| Upland sandpiper (*Bartramia longicauda*) | | | (VU) | | **wet meadow/ grassland** |
| Whimbrel (*Numenius phaeopus*) | VU* | VC | FC | VC | **coastal and estuarine sand beaches and mud flats, saltmarsh** |
| Long-billed curlew (*Numenius americanus*) | U* | VU (FC) | (FC) | VU (FC) | **dry grassland, farmland; estuarine mud flats,** saltmarsh |
| Bar-tailed godwit (*Limosa lapponica*) | | | | R | **coastal and estuarine sand beaches and mud flats** |
| Marbled godwit (*Limosa fedoa*) | C* | FC (FC) | R | FC (FC) | **coastal and estuarine sand beaches and mud flats,** exposed shorelines of interior ponds and lakes |
| Ruddy turnstone (*Arenaria interpres*) | VU | C | | FC | **coastal rocky shore, sand beaches, mud flats** |
| Black turnstone (*Arenaria melanocephala*) | C | C | | C | **coastal rocky shore** |
| Surfbird (*Aphriza virgata*) | C | C | | C | **coastal rocky shore** |
| Red knot (*Calidris canutus*) | VU | VC | R | U (R) | **estuarine sand and mud flats,** coastal sand beaches |

| Species | Abundance by season[a] Winter | Spring | Summer | Fall | Habitat |
|---|---|---|---|---|---|
| Sanderling (*Calidris alba*) | VA | VA (R) | VU | VA (U) | **coastal sand beaches,** estuarine sand and mud flats, coastal rocky shore |
| Semipalmated sandpiper (*Calidris pusilla)* | | VU (U) | | U (U) | **exposed shoreline of shallow ponds,** mud flats |
| Western sandpiper (*Calidris mauri*) | VC* | VA (U) | U | VA (C) | **coastal and estuarine sand beaches, mud flats,** and salt marsh; **exposed shoreline of shallow ponds and lakes;** freshwater low marsh |
| Least sandpiper (*Calidris minutilla*) | FC | VC (C) | | VC (C) | **estuarine mud flats, salt marsh; exposed shoreline of shallow ponds and lakes; freshwater low marsh** |
| Baird's sandpiper (*Calidris bairdii*) | | VU (U) | | FC (FC) | **coastal sand beaches,** mud flats, **exposed shoreline of shallow ponds and lakes**, **grassy areas, alpine/ subalpine meadow** |
| Pectoral sandpiper (*Calidris melanotos*) | | VU | | C (FC) | **estuarine and freshwater marsh**, mud flats |
| Sharp-tailed sandpiper (*Calidris acuminata*) | | | | U | **estuarine salt marsh,** mud flat edges |
| Rock sandpiper (*Calidris ptilocnemis)* | FC | FC | | FC | **coastal rocky shore** |

| Species | Abundance by season[a] | | | | Habitat |
|---|---|---|---|---|---|
| | Winter | Spring | Summer | Fall | |
| Dunlin (*Calidris alpina*) | VA | VA (U) | U | VA (VU) | **coastal and estuarine sand beaches and mud flats, flooded fields**, rocky shores |
| Curlew sandpiper (*Calidris ferruginea*) | | | | R | estuarine marsh, sand beaches, mudflats; freshwater low marsh |
| Stilt sandpiper (*Calidris himantopus*) | | | | VU (VU) | **fresh and brackish marsh; sewage lagoons,** flooded fields |
| Buff-breasted sandpiper (*Tryngites subruficollis*) | | | | VU | **grassy areas, coastal sand beaches** |
| Ruff (*Philomachus pugnax*) | | | | VU | **estuarine mud flats, salt marsh; flooded fields, shallow ponds** |
| Short-billed dowitcher (*Limnodromus griseus*) | | VA (R) | FC | VA (VU) | **estuarine mud flats,** coastal sand beaches, flooded fields, freshwater areas |
| Long-billed dowitcher (*Limnodromus scolopaceus*) | FC | C (VC) | | VC (VC) | **exposed shoreline of shallow ponds and lakes; estuarine mud flats (winter), freshwater marsh** |
| Common snipe (*Gallinago gallinago*) | FC (U) | U (FC) | U (FC) | FC (FC) | **estuarine and freshwater marsh; flooded grassy fields, farmland;** |
| Wilson's phalarope (*Phalaropus tricolor*) | | U (FC) | VU (FC) | VU (FC) | **ponds and lakes, freshwater marsh, sedge meadows** |

| Species | Abundance by season[a] | | | | Habitat |
|---|---|---|---|---|---|
| | Winter | Spring | Summer | Fall | |
| Red-necked phalarope (*Phalaropus lobatus*) | | A (FC) | | A (FC) | **marine waters; ponds and lakes** |
| Red phalarope (*Phalaropus fulicaria*) | U | FC | | VC | **off-shore marine waters** |

**VA** = Very Abundant (over 1,000 individuals observed per day), **A** = Abundant (200-1,000 individuals per day), **VC** = Very Common (50-200 individuals per day), **C** = Common (20-50 individuals per day), **FC** = Fairly Common (7-20 individuals per day), **U** = Uncommon (1-6 individuals per day), **VU** = Very Uncommon (more than 6 individuals per season in the region, but not seen every day), **R** = Rare (1-6 individuals per year in the entire region). The list does not include very rare (over 6 total records), casual (2-6 records), or accidental (1 record) species in the region.

[a] Winter refers to the period of local residency following autumn migration. The winter period for most species is November through March. Spring migration for most species is generally April through mid-May although some species begin migrating in Washington during March and others extend into June. Fall migration extends from late June to late October; some fall migrants occasionally remain in Washington until mid-November.

Other species, for which adequate information is lacking, are likely at risk of population-level impacts due to the vulnerability of their primary habitats (species to which Page and Gill [1994] assigned high vulnerability scores [a score $10 is used here to define 'high'] include American avocet, black-necked stilt, common snipe, killdeer, marbled godwit, snowy plover, upland sandpiper, willet, and Wilson's phalarope) and may be declining (Paulson 1992, Morrison et al. 1994b), although population monitoring data are generally lacking (see exceptions above). Finally, a number of species, including red knot, and various species of plovers, curlews, godwits, and dowitchers suffered substantial, if not catastrophic, population declines between 1870 and 1927 in response to unregulated hunting (Page and Gill 1994; see Cooke 1910, Forbush 1912, Grinnell et al. 1918). Populations of some of these species have not recovered and the likelihood of recovery appears low due to the negative effects of additional or more recent impacts, such as habitat loss (Paulson 1993, Page and Gill 1994).

## HABITAT REQUIREMENTS

Most shorebird species exhibit unique migratory strategies that include preferences for specific habitat components (Davidson and Stroud 1996). Research on habitat selection by birds indicates that a range of habitats may be used although certain habitats are preferred and selected when possible (Fretwell and Lucas 1970). Although research on habitat selection by shorebirds has not been conducted in Washington, the habitat preferences of most species are obvious, assuming the predominant patterns of distribution and abundance reflect habitat preference (Ruggiero et al. 1988; Table 1). Some secondary habitats are used on occasion, however, and may be locally important, particularly during periods of adverse weather or depletion of food sources (Warnock et al. 1995, Davidson and Stroud 1996).

### Coastal Environments

Most shorebirds in Washington occur as migrants or winter residents (Table 1). During the nonbreeding period, most can be found concentrated at beach or estuarine sites where fat and protein reserves required for overwintering or continued migration are replenished (Evans et al. 1991). The primary habitat requirements of these birds relate to the availability of adequate foraging and roosting areas. The foraging requirements of many shorebirds in western Washington are met primarily in estuarine ecosystems associated with silt or silt/sand intertidal areas and adjacent beaches or salt marshes, where tidal mud flats provide foraging substrates for many species. Black-bellied plover, dunlin, western sandpiper, and dowitchers forage on mud flats with high levels of silt, whereas semipalmated plovers and sanderlings forage in sandy or silt/sand areas (Paulson 1993). Other species, such as rock sandpiper, surfbird, and wandering tattler are found almost exclusively along rocky intertidal shores (Paulson 1993). Many species in eastern Washington use wet meadows, flooded fields and other areas of shallow water. The habitat associations of shorebirds in Washington are summarized in Table 1.

As a group, shorebirds are behaviorally and morphologically adapted to forage in a rather narrow range of microhabitat conditions (Burton 1974, Gerritsen and van Heezik 1985), including exposed tide flats or beaches, shallow water, salt marshes, and even open water. Consequently, the selection of invertebrate prey by shorebirds during the nonbreeding season is related to shorebird morphology and environmental factors that influence prey availability. These factors include tidal range, tidal exposure, wave action and tidal current, substrate slope, sediment mobility, organic pollution, local or regional climate, microhabitat conditions, and invertebrate behavior (Bryant 1979, Pienkowski 1981, Quammen 1982, Ferns 1983, Grant 1984, Hicklin and Smith 1984, Gerritsen and van Heezik 1985, Reise 1985, Esselink et al. 1989, Hockey et al. 1992, Beukema et al. 1993, Nehls and Tiedemann 1993, Wanink and Zwarts 1993, Zwarts and Wanink 1993).

Shorebirds use a variety of habitats for roosting. They often roost in salt marshes adjacent to intertidal feeding areas, even when these areas are extremely limited in size (Brennan et al. 1985, Buchanan 1988). Shorebirds at Grays Harbor and Willapa Bay often roost in large flocks on Pacific beaches, occasionally concentrating near the mouths of small creeks where they bathe and preen (Buchanan 1992). In some areas, shorebirds roost on natural and dredge spoil islands and on higher elevation sand beaches (Herman and Bulger 1981, Brennan et al. 1985). Some species also roost in fields or other grassy areas near intertidal foraging sites (Brennan et al. 1985, Butler 1994); shorebirds may forage at these or other roost sites if suitable prey are present. Shorebirds occasionally roost on pilings, log rafts, floating docks, and other floating structures when natural roost sites are limited (Buchanan 1988; Wahl 1995; J. Buchanan, unpublished data).

Shorebirds will fly considerable distances between foraging and roosting locations where roost sites are limited (Page et al. 1979). Distances >16 km (10 mi) have been documented (Symonds et al. 1984, Buchanan et al. 1986). On rare occasions, some species (i.e., dunlins) will engage in continuous flight during the high tide period, even though suitable roosting habitat is available (Prater 1981, Brennan et al. 1985). The reason for this behavior is not understood. In addition, shorebirds will also fly for extended periods when disturbed at a roost site. The energetic costs associated with extensive flights at or among roosting and foraging locations are not well understood.

Other habitats used by shorebirds in this region include pasture and agricultural land. Thousands of shorebirds roost (and occasionally forage) in pastures near Raymond and Bay Center on Willapa Bay during winter and spring migration (Buchanan and Evenson 1997). Large concentrations of roosting birds have been observed on fallow fields at Nisqually delta, Skagit Bay, Samish Bay, Lummi Bay, and adjacent to other large estuaries in northern Puget Sound and the Fraser River Valley (Brennan et al. 1985, Butler 1994, Wahl 1995, Evenson and Buchanan 1997). This type of habitat use has been documented in other areas (Townshend 1981; Colwell and Dodd 1995, 1997; Rottenborn 1996).

Use of artificial wetlands by shorebirds has not been documented in Washington. However, many species of shorebirds, including at least 12 species that occur in western Washington, used managed coastal wetlands in South Carolina (Weber and Haig 1996) indicating that such habitats, if suitable, would likely be used in this state. Salt marsh created at the Jay Dow Sr. wetlands in northeastern California provides important habitat for shorebirds migrating through and breeding in that region (Robinson and Warnock 1996). Similarly, salt evaporation ponds are an important habitat used by over-wintering and spring migrant western sandpipers in San Francisco Bay (Warnock and Takekawa 1995) and by shorebirds in other parts of the world (Davidson and Evans 1986, Martin and Randall 1987, Sampath and Krishnamurthy 1988, Velasquez and Hockey 1992). Shorebirds also forage, usually in comparatively small numbers, in sewage lagoons associated with waste treatment facilities.

Shorebirds are generally site-faithful to specific wintering areas (Townshend 1985, Myers et al. 1986) although some individuals may move considerable distances among sites (Warnock et al.

1995, Warnock 1996). This fidelity to particular sites has important ramifications for conservation management and mitigation. For example, because shorebirds do not settle in their winter quarters in a random manner, but rather return to areas used in previous years, mitigation efforts must recognize that habitat loss will most likely result in density dependent competition (e.g., greater competition for the same level of resources due to a greater density of birds at a given site) at other sites in the region (see the "Habitat Loss" section below).

### Freshwater Environments

Most shorebirds that forage in freshwater areas require ponds and pools that have exposed shorelines or that are shallow enough to allow foraging by wading birds. As with estuarine sites, the availability of appropriate prey (e.g. various invertebrates) and roost sites are important habitat requirements.

Locally nesting species have specific nest site requirements. Killdeer and spotted sandpiper both nest on gravel/cobble substrates, however they often occupy vastly different environments (Paulson 1993). Killdeers nest in habitats including dry lake beds, short-grass fields, and unpaved margins of roadways. In contrast, spotted sandpipers typically nest where there is herbaceous cover in sandy or rocky substrates along creeks, rivers and lakes in both forested and arid environments (Oring et al. 1997). American avocets, black-necked stilts, common snipes, and Wilson's phalaropes also nest in Washington, primarily in the eastern part of the state. Avocets and stilts nest in rather open areas in or near marshes or other bodies of water, while phalaropes and snipes nest in wet meadows and marshes (Paulson 1993). Other habitats used by shorebirds include marshes, pastures, flooded fields, reservoirs, impoundment drawdowns, sewage treatment ponds, stormwater wetlands, and other artificial wetlands (Rundle and Fredrickson 1981, Perkins and Lawrence 1985, Duffield 1986, Paulson 1993). Habitat associations of interior species are summarized in Table 1.

## LIMITING FACTORS

### Habitat Loss

*Effects of Habitat Loss or Degradation During the Nonbreeding Season* - During the past century the amount of coastal estuarine wetlands in North America has been severely reduced (Dahl 1990). In Washington, approximately 66% of the coastal wetlands were destroyed over this period (Boule et al. 1983). Most of Washington's wintering and migrant shorebird species are dependent on these estuarine areas for essential foraging and roosting requirements. The most typical form of habitat loss occurs when wetlands or intertidal areas, including roost sites (Burton et al. 1996), are filled for development purposes (Page and Gill 1994).

Activities that degrade rather than destroy habitat also have the potential to impact shorebirds. Temporary or permanent reductions of habitat quality may reduce foraging efficiency and increase shorebird energetic requirements and/or mortality rates. Mineral extraction activities such as removal of sand from coastal beaches (Phipps 1990) or gravel from river beds, may degrade or destroy foraging, roosting and nesting habitat used by shorebirds.

For some shorebird populations, the loss of nonbreeding habitats, including roosting sites (Burton et al. 1996), results in increased density-dependent mortality (Sutherland and Goss-Custard 1991). This increased mortality occurs when shorebirds are forced to leave degraded or destroyed sites and settle elsewhere. Such movement to other sites increases the density of birds at remaining sites and results in greater competition for limited resources (Goss-Custard 1977, Evans et al. 1979, Goss-Custard 1979, Schneider and Harrington 1981, Goss- Custard 1985, Moser 1988, Lambeck et al. 1989) because of higher rates of prey depletion and increased rates of competitive interference (Goss-Custard and Durell 1990, Sutherland and Goss-Custard 1991, Evans 1991). It is likely that these movements force some birds to occupy lower-quality sites where competition for marginal resources is more intense (Evans 1976, Sutherland and Goss-Custard 1991). These movements may have a greater impact on juvenile shorebirds (Goss-Custard and Durell 1987) and may therefore considerably influence population structure; this may have occurred in a wintering population of dunlins in Europe (Sutherland and Goss-Custard 1991).

For shorebird species that forage on invertebrates associated with kelp windthrow, the health of offshore kelp forests may be important for maintaining stable populations in this region. In coastal California, linear densities of spotted sandpiper, wandering tattler, whimbrel, black turnstone, and ruddy turnstone were higher on the Palos Verdes Peninsula in 1985-86, after offshore kelp forests had been restored, than in 1969-73 when kelp was absent (Bradley and Bradley 1993). Although these relationships were highly significant, the authors cautioned against generalizing their results to other regions because other factors may have partially contributed to the observed population changes.

*Effects of Habitat Loss or Degradation on Reproductive Capability* - The loss or degradation of habitat at migratory stop-over sites may influence survival rates and annual productivity of shorebirds on their Subarctic/Arctic breeding grounds. The timing of arrival at the breeding grounds sometimes occurs during periods of adverse weather or depleted prey availability. Survival at this time is more likely if the birds have accumulated sufficient fat and protein reserves at temperate staging sites (Morrison and Davidson 1989). Some shorebirds carry more fat than is needed to make flights between staging areas and the breeding range (Davidson and Evans 1989, Evans and Davidson 1990) and it is thought that these reserves provide insurance in the event of adverse conditions during migration or upon arrival at the breeding grounds. When shorebirds are delayed at staging areas or are otherwise unable to adequately accumulate these body reserves before or during migration, they are more likely to experience nest failure due to late arrival or poor physiological condition at the breeding grounds (Davidson and Evans 1989, Evans and Davidson 1990). Consequently, marginal environmental conditions at wintering or migratory staging areas in Washington may influence shorebird productivity at breeding areas thousands of miles away.

*Bivalve Management* - A number of economically important bivalve species are produced and harvested in Washington's sheltered marine waters, but there have been no studies on the relationship between their presence or harvest and shorebird behavior or abundance. The geoduck clam (*Panopea abrupta*) is generally harvested in waters $6 m deep at mean low low-water or $200 m from shore and its management therefore does not appear to have a direct bearing on shorebirds. Other bivalve species, however, are managed in intertidal areas that are also used by shorebirds. These areas are either privately owned or leased from the Washington Department of Natural Resources.

Bivalve management, when conducted on silt or silt-sand tide flats, clearly alters substrate conditions (Simenstad et al. 1991). These substrate alterations influence the quality of sites and in some cases may render a site less suitable or unsuitable for shorebird species associated with fine-silt substrates. The only study to address shorebird response to aquiculture activities, conducted in Tomales Bay, California, found far lower densities of dunlins and western sandpipers in aquiculture plots than in adjacent control plots (Kelly et al. 1996). The significance of substrate alteration and the resulting changes in suitability of foraging habitat to local shorebird populations is unknown. It should be noted that some shorebirds may benefit from bivalve management. The density of willets, an uncommon species in Washington, was greater in aquiculture plots than in control plots at Tomales Bay, California (Kelly et al. 1996). Shorebirds in Washington, particularly greater yellowlegs, occasionally forage in tidal pools associated with aquiculture operations (J. Buchanan, unpublished data). The significance of this potential association is also unknown.

*Water Diversion* - Habitat loss in interior regions of Washington occurs primarily when wetland areas are drained and used for agricultural or development purposes. It is possible that changes in the water table resulting from irrigation demands on local drainages has reduced or eliminated some areas of wetland or moist habitats (Hallock and Hallock 1993, Neel and Henry 1996). Such habitat losses may increase density-dependent effects on shorebirds in the manner described above.

*Water Salinization* - Changes in water chemistry, manifested through salinization, may adversely effect shorebirds or their habitats in the Columbia Basin. Although a natural phenomenon in the intermountain west (defined as the portion of western North America that lies between the Cascade and Rocky Mountain ranges), water salinization increases as greater demands are placed on limited water resources (American Society of Civil Engineers 1990). Water salinization occurs when water is diverted for other uses. Diversion of water typically results in less water delivered to wetlands and other water bodies. As a result, wetlands and ponds become shallower and more saline through evaporative concentration (Rubega and Robinson 1996). The extent to which water salinization has occurred in interior Washington is unknown. In addition, it is not clear how to best manage saline wetlands for shorebirds or other wildlife (Rubega and Robinson 1996).

Salinization may directly effect shorebirds in a number of ways. First, salinization interferes with their ability to regulate water balance through excretion of excess salt (Rubega and Robinson 1996). Although some birds have well developed salt glands that enable them to excrete excess salt (Schmidt-Nielson 1960), it is not clear that all shorebirds have this capability (Rubega and Robinson 1996). An inability to maintain water balance results in dehydration and death (Rubega and Robinson 1996).

Second, water salinization may influence shorebird behavior. Shorebirds in highly saline areas often concentrate near freshwater sources such as springs (Rubega and Robinson 1996; J. Buchanan, personal observation). If these freshwater sources are scarce it is likely that energetic costs will be increased for birds that travel to these sites. Like all birds, shorebirds bathe regularly. It is thought that salinization may increase feather wetting, which in turn may increase thermoregulatory demands (Rubega and Robinson 1996). Water balance and thermoregulatory considerations may be particularly significant to fledglings (Rubega and Robinson 1996).

Water salinization may also result in changes in emergent vegetation as well as in the composition of the invertebrate community (Wolheim and Lovvorn 1995). These changes may influence the composition of shorebirds using particular sites by reducing the species richness of potential prey species (Rubega and Robinson 1996). Research is clearly needed to investigate the relationship between increasing water salinization and the health and behavior of shorebirds that migrate through or nest in the Columbia Basin.

*Effects of Livestock Grazing* - A number of research projects indicate that livestock grazing has a variety of positive and negative effects on shorebirds and their habitats in the interior portion of western North America (Powers and Glimp 1996). The direct effects, including trampling and disturbance, are negative, whereas the indirect effects are either positive or negative and include habitat changes and factors related to foraging and predation (Powers and Glimp 1996). The potential significance of these effects are thought to be related to the species of grazer and the timing and distribution of grazing (Powers and Glimp 1996).

The effects of trampling by livestock include destruction of eggs or nests (Rohwer et al. 1979, Guldemond et al. 1993), abandonment of disturbed nests (Delehanty and Oring 1993), and increased time adult birds spend away from their nests (Graul 1975), which likely results in increased exposure of eggs. Although each of these effects has been noted in shorebirds (Powers and Glimp 1996), research on these topics is lacking from the intermountain west.

Livestock may also impact shorebird habitats by altering attributes of the environment. For example, livestock grazing can alter vegetation composition, compact soil, and increase erosion (Kadlec and Smith 1989, Powers and Glimp 1996). These changes have been demonstrated to result in reduced populations of invertebrates (Mono Basin Ecosystem Study Committee 1987), reduced use of habitats by shorebirds (Bowen and Kruse 1993), and increased egg depredation and predation upon chicks and adults (Redmond and Jenni 1986, Bowen and Kruse 1993).

Conversely, livestock grazing has certain demonstrated or potential benefits to shorebird habitats, depending on the timing and intensity of grazing. Grazing was thought to control the growth of vegetation that would otherwise have been too tall or dense to allow use by shorebirds (Crouch 1982, Kohler and Rauer 1991, Nilsson 1997). In addition, several studies in non-arid regions indicate that grazed lands supported greater populations of invertebrate prey species and that shorebird foraging and body condition was enhanced at those sites (Galbraith 1987, Granval et al. 1993). It is unknown whether these potential benefits of livestock grazing would occur in the intermountain west.

*Effects of Exotic Plants* - Three exotic species of cordgrass (*Spartina* spp.) have invaded the intertidal areas of Washington (Frenkel and Kunze 1984). Although *Spartina alterniflora* was introduced to Willapa Bay in 1894, and was recognized as a potential problem in 1942, its spread has increased dramatically in the past decade (Mumford et al. 1991). Cordgrass grows in dense stands that effectively trap sediments; this process leads to changes in substrate elevation that may substantially degrade the original salt marsh environment (Sayce 1988, Landin 1991). Research in Europe indicates that tideflat areas with *Spartina* growth have lower densities of the invertebrate prey of shorebirds (Millard and Evans 1984, Atkinson 1992). Moreover, an association between the spread of *Spartina* and a decline in shorebird abundance was reported in Great Britain (Goss-Custard and Moser 1988). Observations near the mouth of the Willapa River in Willapa Bay in spring 1998 indicate that extensive areas used by red knots and western sandpipers in the early 1980s are now covered by cordgrass and no longer appear to be used by these shorebirds (Chris Chappell, personal communication). Consequently, although the information for North America is rather limited, it appears that the colonization and alteration of tideflats by cordgrass has the potential to influence the availability of shorebird foraging and roosting habitats in Washington.

Another exotic species, purple loosestrife (*Lythrum salicaria*), has invaded the Columbia Basin (Engilis and Reid 1996). Loosestrife is a dense, woody plant that can grow to over two meters in height along the margins of ponds, lakes and wetlands. This fast-growing plant can render invaded shoreline areas unsuitable for shorebirds. Additional exotic species that may cause habitat degradation, although likely at a lesser scale, include *phragmites* which grows along salt marsh margins, and reed canarygrass (*Phalaris arundinacea*), which grows along margins of freshwater wetlands and flooded fields that might be used by shorebirds.

*Effects of Exotic Vertebrates and Invertebrates* - Numerous exotic vertebrate and invertebrate species have been introduced to coastal and interior wetlands (Carlton and Geller 1993). The common carp (*Cyprinus carpio*) was introduced to many wetland areas in the intermountain west and appears to be degrading wetland habitats (Engilis and Reid 1996). The foraging behavior of this exotic species disturbs aquatic plant beds which increases turbidity and reduces photosynthetic activity by submerged plants (Robel 1961). The likely consequence is a change in wetland vegetation composition and a reduction in invertebrate populations.

A number of exotic marine invertebrates, transported and introduced via ballast water introduction (Cordell 1998), have the potential to impact shorebird prey populations in Washington's estuaries. The Asian clam (*Potamocorbula amurensis*) has recently become established in San Francisco Bay, California (Carlton et al. 1990). The invasion of this clam was very rapid and in some areas of San Francisco Bay it now dominates the macrobenthic fauna (Nichols et al. 1990). We have no evidence to suggest that this species has colonized estuarine sites in Washington. The European green crab (*Carcinus maenas*) was documented in coastal estuaries of Washington in 1998. It too has the capability to dramatically alter the macrofaunal community of marine estuaries. Such changes would be potentially deleterious to shorebird and other wildlife populations associated with marine estuaries.

Similarly, various Asian copepods have recently been introduced via ballast waters to coastal estuaries in the Pacific Northwest (Cordell 1998, Cordell and Morrison 1996). Although the outcome of these invasions is not clear, potentially significant deleterious effects similar to those associated with other invasions of this type are likely to occur (Carlton et al. 1990, Nichols et al. 1990, Cordell 1998).

*Utility Lines* - Collisions with utility lines have been documented for a wide variety of bird species including shorebirds (Kitchin 1949, Bevanger 1994, Brown and Drewien 1995, Janss and Ferrer 1998). Placement of utility lines adjacent to intertidal areas may degrade habitat quality by increasing the likelihood of in-flight collisions (Scott et al. 1972, Lee 1978). Fatal injuries to shorebirds following collisions with utility lines have occurred where utility lines were situated adjacent to intertidal foraging areas in western Washington and at the Fraser River estuary in British Columbia (Kitchin 1949; J. Buchanan, unpublished data; R. Butler, personal communication; S. Richardson, personal communication).

*Wind Turbines* - Mortality of shorebirds has been documented at wind turbine sites in the Netherlands (Musters et al. 1995, 1996) and in the United States (Erickson et al. 2001), although the rate of documented mortality was generally low. It is likely, however, that mortality would be greater at complexes of turbines situated along flight corridors used by large concentrations of shorebirds. Wind turbine sites in southeastern Washington occur near areas used by a relatively small flyway of migrating shorebirds, but the potential impact of the turbines on those shorebirds is currently unknown. There are relatively few wind turbine sites in Washington at present, but it is expected that many such sites will be established in the near future as the technology for managing this efficient source of energy is refined. The significance of wind turbines as a source of mortality will likely depend on the number and location of these complexes built in the coming years.

*Other Potentially Hazardous Structures* - One million or more birds are killed annually across North America in collisions with structures such as skyscrapers and communication towers (see www.towerkill.com [1998]). Because of their great height, these structures are a hazard to low-flying migrant birds. Even the illumination from safety lights is thought to confuse birds, causing circling behavior around the structure that increases the likelihood of collisions with support cables or the structure itself (Avery et al. 1976). As of November 1998, there were 241 towers exceeding 61 m (200 ft) in Washington, including 19 towers of at least 152 m (500 ft). Many of these towers are located in the Puget Trough; the presence of these towers may be a mortality factor for shorebirds that overwinter and/or migrate through this region. The potential magnitude of this factor has not been addressed (see www.towerkill.com [1998]). Shorebirds have also been documented colliding with coastal lighthouses; multiple incidents involving red-necked phalaropes occurred at the Destruction Island lighthouse in 1916 (Bowles 1918). Such occurrences are poorly documented, but this is likely related to limited access and search efforts at such sites.

## Pollution

*Chemicals and Heavy Metals* - Research from other temperate coastal regions indicates that rather high levels of organochlorine contaminants (White et al. 1980, White et al. 1983) and heavy metals (Goede 1985, Goede and de Voogt 1985, Blomqvist et al. 1987, Ferns and Anderson 1994) occur in shorebird tissues. Although the effects of these contaminants on shorebirds are not known, physiological and behavioral abnormalities associated with high contaminant levels have been reported for other temperate marine bird species (Gilbertson et al. 1976, Gilbertson and Fox 1977, Sileo et al. 1977, Fox et al. 1978).

Contaminant levels have been reported in black-bellied plovers, dunlins, and western sandpipers wintering in western Washington (Schick et al. 1987, Custer and Myers 1990). Both studies found levels of organochlorine contaminants below those known to affect the survival or reproduction of shorebirds. However, some spring migrants from Grays Harbor carried very high DDE residues (Schick et al. 1987). Black-bellied plovers from 2 Puget Sound sites carried low levels of mercury and elevated levels of selenium (Custer and Myers 1990). In addition, dunlins occasionally ingest lead shot (Kaiser et al. 1980, J. Buchanan, unpublished data), but residue levels of lead in shorebirds are unreported for this area. Given the lack of current data on concentrations of organochlorine and heavy metal contaminants in shorebirds in this area (Schick et al. 1987, Custer and Myers 1990), it is difficult to assess the potential current effects related to these contaminants. Other contaminants, such as organophosphorus insecticides, also occur in the environment; there is no information on the presence or effects of these contaminants on shorebirds in this region (Morrison 1991).

Contaminants known or suspected to have originated from upland agricultural areas have been documented in shorebirds (White et al. 1980, Zinkl et al. 1981, DeWeese et al. 1983, White et al. 1983, Schick et al. 1987, Custer and Mitchell 1991). The discovery of contaminants (i.e., selenium) in waterfowl and wading birds that use freshwater marshes (Ohlendorf et al. 1986, Saiki and Lowe 1987, DuBowy 1989, Williams et al. 1989) suggests that common snipe, American avocet, black-necked stilt, and Wilson's phalarope may be vulnerable to exposure to a similar variety of contaminants. Two incidents of dunlins killed after exposure to agricultural chemicals have been reported from northern Puget Sound (Lora Leshner, personal communication). In California, killdeers and dunlins died after ingesting grain poisoned by strychnine (Warnock and Schwarzbach 1995); the likelihood of such an event occurring in Washington is unknown.

Heavy metals and other contaminants are present in naturally-occurring and dredged sediments in estuaries, and accumulate in fish, birds, mammals, and invertebrates (Goerke et al. 1979, Seelye et al. 1982, Duinker et al. 1984). Contaminants can also be released from sediments by bait digging in the intertidal zone (Howell 1985). Intake of these contaminants occurs when shorebirds forage in intertidal areas. Other sources of pollutants include waste discharge, which has been associated with the disappearance of invertebrate prey species of shorebirds in the Netherlands (Esselink et al. 1989, van Impe 1985). The significance of waste discharge on shorebird abundance or physical condition in this region is unknown.

*Oil Pollution* - In a summary report on the potential effects of oil spill contamination in northern Puget Sound and the Strait of Juan de Fuca, 10 shoreline habitat types were identified in the order of their sensitivity to oil contamination (Kopenski and Long 1981). Three of the four most sensitive habitat types - sheltered marshes, sheltered tidal shores, and exposed tidal flats - are primary foraging and roosting habitats for numerous shorebird species. The most abundant wintering shorebird species to use these habitats, the dunlin, is considered highly sensitive to oil spill pollution (Vermeer and Vermeer 1975). Other species, such as the sanderling, are likely sensitive as well (Chapman 1984). Certain species that use rocky shoreline habitats may be less vulnerable to some impacts from oil spills (Smith and Bleakney 1969), since oil would have a shorter "residence time" on rocky shorelines exposed to high wind and wave energy. This reduces the time period during which birds would be exposed to oil, although short-term impacts to these species can still be substantial (Andres 1997).

Spill-related avian impacts can be manifested in at least 5 ways. First, direct mortality occurs due to a number of factors related to plumage fouling or toxicity (Leighton 1990). Second, reduced invertebrate food supplies caused by oil pollution (Bellamy et al. 1967, Grassle et al. 1980, Maccarone and Brzorad 1995) may result in reduced survival rates if birds are forced to relocate to densely-occupied or less productive areas (Sutherland and Goss-Custard 1991). This is especially true during winter, when foraging efficiency may be constrained by adverse weather, particularly if body-fat reserves are too low to fuel significant emigrations. Third, the activity associated with the actual cleanup of the spill may disturb shorebirds to such an extent that foraging and roosting patterns are disrupted (Burger 1997). Fourth, research indicates that oiled shorebirds spend more time preening and less time foraging after a spill (Burger 1997). Burger

(1997) concluded that this was a potentially negative influence on the condition of the birds upon their departure for migration (and also on their arrival at the breeding grounds; see above), and added that the detrimental effects were magnified by the presence of people (see section on human disturbance). Finally, oiled birds may be more vulnerable to predation, particularly if 1) plumage fouling or thermal stress make them less efficient at avoiding predators, or 2) their marked plumage or altered behavior make them more conspicuous to predators (Curio 1976).

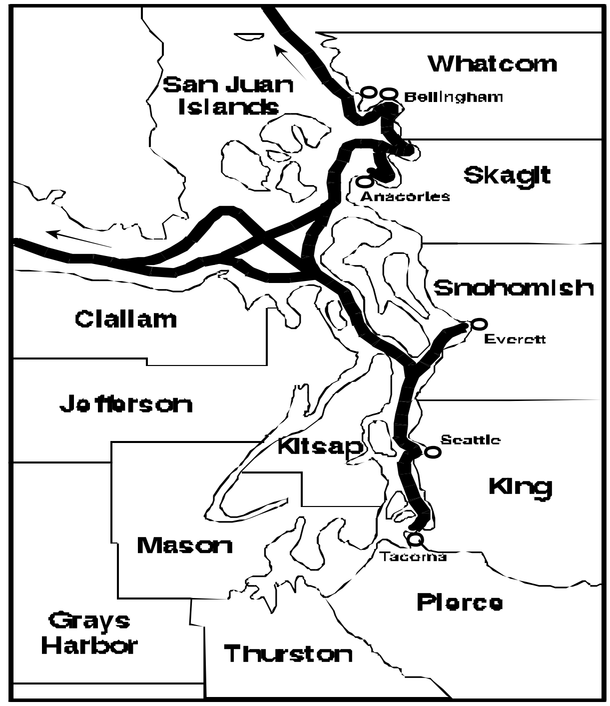

Figure 2: Major shipping lanes in the Puget Sound and the Strait of Juan De Fuca. These lanes extend northwards through the Strait of Georgia, and along Washington's outer coast into the Columbia River.

Recent experience indicates that oil pollution is a significant potential threat to shorebirds in this region. Larsen and Richardson (1990) found that 3,574 of 11,708 shorebirds (mostly dunlins) were still oiled 5 days following the *Nestucca* oil spill off Grays Harbor in December, 1988. This proportion of oiled birds declined over the next 3 weeks, and it was unclear whether the decline was related to self-cleaning, emigration, or mortality. The beaches fouled by this spill support very high overwintering concentrations of sanderlings and roosting dunlins (Buchanan 1992). It is noteworthy that the largest Puget Sound populations of shorebirds in winter, spring, and fall occur at estuaries in close proximity to major shipping lanes and/or oil refineries (Evenson and Buchanan 1995, 1997; Figure 2).

*Other Sources of Pollution* - Plastic-particle pollution has been documented in most marine waters (Coe and Rogers 1997) and occurs when plastic debris (e.g., packaging material) enters the marine environment from land (Liffmann and Boogaerts 1997, Redford et al. 1997) or at-sea sources (Coe and Rogers 1997). The variety of plastic waste present in the marine environment is quite high and differs from one site to the next (Ribic et al. 1997). Debris surveys conducted at the ports of Seattle and Tacoma and on the beach at Olympic National Park reported high amounts of plastic debris; the park survey in 1992 found an average quarterly accumulation of 1729 pieces of plastic debris/km (Ribic et al. 1997). Plastics digestible by wildlife comprised between 44-74% of the debris found in surveys along the west coast of North America (Ribic et al. 1997).

Plastic pollution in marine environments is potentially detrimental to shorebirds and other wildlife after it is intentionally or accidentally ingested. Small particles are ingested by surface feeding marine birds (Baltz and Morejohn 1976, Day et al. 1985) and have been associated with reduced fat deposits (Connors and Smith 1982, Ryan 1988) and perhaps intestinal blockage and ulcerations in other species (Day et al. 1985). Among shorebirds, the red phalarope appears most vulnerable to this type of contamination in Washington (Bond 1971, Connors and Smith 1982, Day et al. 1985), although other shorebird species have been known to ingest plastic particles (i.e., bar-tailed godwit [*Limosa lapponica*] and red-necked phalarope; Robards et al. 1997).

## Human Disturbance

Human disturbance has the potential to influence shorebirds in at least 3 ways (Fox and Madsen 1997). First, substantial disturbances force birds to alter their normal activity patterns resulting in an increase in energetic costs. Second, shorebirds forced to leave an area due to human disturbance may settle in lower-quality alternate habitats. Third, increased energetic costs and use of lower-quality habitats may expose shorebirds to greater risks of predation. The occurrence and potential significance of these patterns is only now beginning to be investigated and understood in North America.

Many human disturbances are related to recreation. Sources of disturbances include beachwalkers, wandering dogs, birdwatchers, hunters, windsurfers, horseback riders, cyclists, vehicles, boats, kayaks, personal water craft (e.g., jet skis), helicopters, and airplanes (Kirby et al. 1993, Goss-Custard and Verboven 1993, Koolhaas et al. 1993, Smit and Visser 1993). In Washington, these types of activities are responsible for both inadvertent and intentional disruption of foraging and roosting behavior (J. Buchanan, unpublished data). Most disturbances from recreational sources are temporary (e.g., birds relocate to a new site following a disturbance). However, cumulative effects of repeated disturbances, particularly during periods of peak human activity (Kirby et al. 1993), or during periods of peak shorebird abundance (e.g., migration; Burger 1986) may be significant (Klein et al. 1995), although this has not been well assessed (Goss-Custard and Verboven 1993). Human disturbance may be most significant in areas where roost sites are limited (Warnock et al. 1995) because the birds do not have alternate sites they can use when disturbed.

*Pedestrian and Vehicular Recreational Activities* - Perhaps the most common type of human disturbance is recreational walking or other travel on beaches. Pedestrian or vehicle traffic on beaches or other areas used by shorebirds negatively affects shorebird distribution, abundance, foraging efficiency, and behavior (Burger and Gochfeld 1991, Pfister et al. 1992, Goss-Custard and Verboven 1993, Kirby et al. 1993). In fact, local population declines of sanderling, semipalmated sandpiper, short-billed dowitcher, and red knot along the Atlantic coast of North America may be related to site disturbance from moderate levels of vehicle traffic (Pfister et al. 1992). Klein et al. (1995) found that several shorebird species were more common in areas further from roads and trails (or dikes) on a wildlife refuge than in similar habitats near roads and trails. Some species (i.e., black-bellied plover, willet) were particularly sensitive to higher levels of vehicle traffic and responded by moving further from roads (Klein et al. 1995). Limited information suggests that black oystercatchers will abandon areas with regular human activity (Ainley and Lewis 1974, Nysewander 1977, Andres 1998); this may be particularly critical in nesting areas.

Human disturbance occasionally escalates to a point where shorebirds are killed. At North Beach, Washington, a beach open to vehicle traffic, roosting flocks of western sandpipers, dunlins, sanderlings, and dowitchers have been intentionally targeted by speeding motorists; at least 480 birds were killed in 2 separate incidents on this beach (R. Schuver, personal communication; M. Cenci, personal communication). Harassment by motorists of roosting shorebirds is not uncommon on Washington beaches (J. Buchanan, personal observation).

*Water-related Recreational Activities* - Shorebirds are also disturbed by recreational activities on water (Weston 1997). Smit and Visser (1993) reported that kayakers represent a potentially important source of disturbance to roosting birds because the small daft of a kayak allows close approach to roost sites in intertidal areas. Disturbance by personal motorized water craft (e.g., jet skis) has been documented at a large roost site in Grays Harbor (L. Vicencio, personal communication). These types of disturbances may occur throughout marine areas of Washington.

*Waterfowl Hunting* - A common human disturbance activity is waterfowl hunting. The noise associated with shotgun blasts disturbs foraging and roosting black-bellied plovers, greater yellowlegs, dunlins, and western sandpipers in Washington and can cause birds to temporarily leave an area (J. Buchanan, unpublished data). In a review of the effects of hunting disturbance on waterbirds (including shorebirds), Madsen and Fox (1995) reported that hunting disturbances can result in temporary disruption of daily activities (foraging, roosting, preening) and displace birds from preferred foraging areas. These responses to hunting disturbance result in greater energetic costs due to under-exploitation of preferred foraging areas. Given that populations of many species may be limited during the winter period the potential significance of the disturbance is clear, though it is unknown whether the level of disturbance from hunting reduces the physical condition or survival of shorebirds in Washington.

Although many shorebird species were hunted formerly (Bent 1927, Page and Gill 1994), the common snipe is the only shorebird game species in Washington. Other species, including dunlin, long-billed dowitcher, and greater yellowlegs, are occasionally shot by hunters who mistake them for snipes (Hainline 1974, J. Buchanan, unpublished data; R. Butler, personal communication; J. Hidy, personal communication). In a small sample of snipe wings submitted anonymously by hunters, 18% of the wings were actually from long-billed dowitchers (Buchanan and Kraege 1998). It is currently unclear whether this source of mortality is as substantive as these preliminary data suggest.

Intentional killing of non-game shorebirds by waterfowl hunters has also been documented at several sites in western Washington, including Samish Bay, Totten Inlet, and Willapa Bay (J. Hidy, personal communication; R. Woods, personal communication, J. Buchanan, unpublished data). The Willapa National Wildlife Refuge is closed to snipe hunting to reduce the likelihood that nontarget species will be shot (J. Hidy, personal communication).

*Aircraft* - Aircraft traffic and military activities can also disturb shorebirds (Smit et al. 1987, Koolhaas et al. 1993, Smit and Visser 1993). In a review of shorebird disturbance factors in Europe, Smit and Visser (1993) found that the distance at which shorebirds flushed varied among sites, suggesting that shorebirds were less habituated to aircraft disturbances at certain sites. Nonetheless, they reported that shorebirds were usually disturbed (e.g., they flushed from foraging or roosting sites) by aircraft flying at <300 m (990 ft). Similarly, shorebirds were more restless on days with jet activity than on days without (Koolhaas et al. 1993). Helicopters disturbed shorebirds at greater distances than other aircraft, although one study showed no disturbance from helicopters flying at 100-300 m (330-990 ft) 2-3 times per hour, suggesting, perhaps, that habituation had occurred to the regular flights (Smit and Visser 1993). Small and slow flying aircraft were one of the most disturbing phenomena in the Wadden Sea area (Smit and Visser 1993). Additionally, ultralight aircraft may cause impacts because of low flights and associated noise, although there are no data on shorebird responses to this potential source of disturbance (Smit and Visser 1993).

## Environmental Conditions, Predation, and Disease

The effects of adverse weather, predation, and disease on the physical condition of shorebirds is important from a management perspective. Although these factors (i.e., general storm patterns, predation) typically operate at a level beyond human influence, their significance may be far greater if coupled with the effects of subsequent human activities (e.g. habitat loss, pollution, disturbance). Consequently, a general understanding of these factors is necessary for effective management.

*Adverse Weather Conditions* - Reduced body mass, emigration, depleted invertebrate food sources, reduced availability of adequate nesting and foraging areas, and outright mortality are known to occur during winter storms or prolonged periods of flooding or drought. The impact of winter storms may be more severe in regions with normally mild weather conditions because shorebirds maintain fat levels and muscle mass (i.e., protein reserves) adequate for survival under the prevailing environmental regime (Davidson 1981, Davidson and Evans 1982, Davidson et al. 1986a, b; Dugan et al. 1981). Unusual storm events therefore have the potential to catch the birds "off guard".

Flood and drought conditions are known to influence habitat use by shorebirds. Drought in interior areas may result in reduced availability of foraging or nesting habitats, particularly for species that use wetlands (Alberico 1993). Significant flooding in estuarine or interior habitats may inundate foraging, roosting or nesting locations for extended periods, and in estuarine areas may deplete invertebrate populations through erosion or scouring of fine intertidal sediments (Ferns 1983). These conditions are unsuitable for certain species and can result in reduced body condition or site abandonment (Strauch 1966, Rundle and Fredrickson 1981, Hands et al. 1991, Warnock et al. 1995). Extensive winter movements (up to 160 km [100 mi]) in response to adverse weather have been documented in California (Warnock et al. 1995) and appear to occur in Washington (Evenson and Buchanan 1995, 1997).

On the other hand, changes in water levels, particularly at interior sites, may create more suitable conditions for certain shorebird species (Rundle and Fredrickson 1981, Hands et al. 1991, Smith et al. 1991, Taylor et al. 1993). Sites that generally lack adequate foraging areas due to extremely high or low water levels will be used by shorebirds when foraging opportunities are created by changing water levels.

*Global Warming* - There is currently considerable debate regarding the ecological significance of global warming. A change in global temperature would likely have both predictable and unforeseen impacts on shorebirds. Changes in sea level will likely alter the distribution and extent of estuarine areas, and may reduce the area of intertidal and saltmarsh habitats available to shorebirds (Lester and Myers 1989-90). Other potential responses to global warming include changes in migration timing, migration routes, extent and quality of breeding habitats, and the availability of prey.

Other changes related to climatic conditions are occurring along the Pacific coast of North America. Recent research indicates that significant warming has occurred in waters of the California Current. This warming has been linked to declines in zooplankton and seabird populations (Roemmich and McGowan 1995, Veit et al. 1996). Changing conditions in offshore waters may influence the distribution and abundance of phalaropes migrating through the region. In addition, rock sandpiper numbers have declined substantially in the southern portion of their wintering range during this period of oceanic warming (Buchanan 1999).

*Predation* - Predation is a potentially significant limiting factor because it is a substantial source of mortality among shorebirds. The overall mortality rate of most shorebird species is very high (Martin-Löf 1961, Boyd 1962, Soikkeli 1967, Gromadzka 1983; see Warnock et al. 1997). The presence of predators in an area typically results in heightened levels of vigilance by shorebirds (Metcalfe 1984). This enhanced vigilance, in combination with other sources of disturbance, can have a potentially significant effect on shorebird activity schedules and physical condition (Burger 1997). Perhaps the most significant predators of shorebirds in Washington are the peregrine falcon (*Falco peregrinus*) and merlin (*F. columbarius*), both recognized as priority species in Washington. An estimated 21% of a wintering population of dunlins in California were taken by falcons (Page and Whitacre 1975). In some situations predation by raptors may influence the latitudinal distribution of wintering shorebirds (Whitfield et al. 1988) as well as population structure (Townshend 1984). Some studies show that juvenile shorebirds are preferentially selected by raptors, or that they are more vulnerable to predation because they roost in atypical habitats (Kus et al. 1984, Townshend 1984). Shorebirds also respond to the presence of mammalian predators such as rats; this may be most significant at nocturnal roosts (Burton et al. 1996).

*Disease* - The significance of disease for most shorebird species is unknown. However, outbreaks of avian cholera and botulism Type C are capable of killing thousands of birds, including shorebirds (Kadlec and Smith 1989).

## Political and Management Constraints

Shorebirds as a group are characterized by annual, round-trip flights of enormous distances between wintering and breeding areas. This life history attribute alone makes it difficult for management agencies to identify species of concern and facilitate meaningful protection strategies. Factors that influence the health of shorebird populations may operate on the breeding grounds, the wintering grounds and/or along flyways. Consequently, managing shorebirds, particularly the highly migratory species, requires that these factors be addressed wherever they occur.

Current methods of identifying and protecting species of concern across broad geographical areas are somewhat limited in their utility (unless the species is listed by federal governments). For example, a species listed as threatened or endangered at the state or province level generally has no special standing elsewhere (except for basic protections under the Migratory Bird Treaty Act). This creates potential difficulties for management of a state-listed species if a limiting factor exerts significant influence during migration through a state or province where the species (does not breed and) is not listed. States tend to list only those species that have breeding populations within state boundaries and generally focus on determining a species' status within the state. In short, it is currently difficult, if not impossible, for states (and likely provinces) to effectively enact legal protection for species for which there is local or regional, but not federal, concern.

## MANAGEMENT RECOMMENDATIONS

These management recommendations are based on a combination of locally and regionally important conservation issues. The following sections contain a spectrum of management recommendations that land owners, resource managers, and others can use to reduce impacts to shorebirds or to improve shorebird habitats. These recommendations address regional or large scale conservation issues, as well as site-specific actions that may be meaningful to local sub-populations. Some of these recommendations can be implemented by landowners and local governments, while others are more policy oriented, and need to be addressed by state and federal agencies, and conservation organizations. Because of the broad range of shorebird distributions and their dynamic life history characteristics, it is important to understand these management issues at various spatial and temporal scales.

### Habitat Identification and Preservation

*Identify important local and regional sites* - One of the first tasks required to protect shorebird habitat is to identify important local and regional sites. British workers have developed a system to evaluate site populations by comparing them to national, international and flyway populations (Prater 1981). Field work to identify locally and regionally important sites is ongoing in much of western North America (Page and Gill 1994; G. Page, personal communication), and many important sites in western Washington have been identified (Buchanan and Evenson 1997, Evenson and Buchanan 1997). Additional work is needed for the migration periods in eastern Washington, the fall migration period in western Washington, and for the group of rocky shoreline species along the Washington coast.

Wetland habitats of all sizes support shorebird populations in Washington. In North America, standards set forth by the Western Hemisphere Shorebird Reserve Network specify that sites which support at least 20,000 shorebirds or at least 5% of the flyway population are of regional importance (Myers et al. 1987a; Harrington and Perry 1995; I. Davidson, personal communication). This strategy appears to effectively identify several of the major estuarine sites in Washington. However, recent research in Puget Sound indicates that numerous sites support populations of <5,000 shorebirds, and that cumulatively these sites may account for as much as 20-50% of the Puget Sound shorebird population (Evenson and Buchanan 1995, 1997), indicating a need to recognize the importance of assemblages of smaller sites. This may also be particularly important for some shorebirds that migrate through the Columbia Basin (Robinson and Warnock 1996, Skagen 1997).

*Preserve remaining wetland habitat* - Preservation of remaining wetland habitat should be a priority for shorebird conservation programs. Locally and regionally important sites should be purchased to reduce the loss or degradation of habitat important for shorebirds and other wildlife. Following an assessment of water needs and a determination of salinization significance, efforts should be made to insure the availability of high-quality water for important wetlands and wetland complexes in the Columbia Basin. In a review of coastal wetland conservation strategies, Bildstein et al. (1991) recommended the development of new protective and regulatory legislation, and more effective enforcement of existing laws concerning wetland use.

## Land Use Assessment

*Assess livestock grazing in habitats used by shorebirds for potential impacts* - Research indicates a number of direct and indirect impacts on shorebirds or their habitats due to grazing livestock (Powers and Glimp 1996). Negative impacts described elsewhere include the destruction of eggs or nests (Rohwer et al. 1979, Guldemond et al. 1993), abandonment of disturbed nests (Delehanty and Oring 1993), and adult birds spending an increased time away from their nests (Graul 1975), which likely results in increased exposure of eggs.

*Assess commercial sand and gravel extraction from beach and riverine areas for potential impacts to shorebirds* - Certain beach and riverine areas are important foraging, roosting, or nesting areas for shorebirds (Buchanan 1992, Paulson 1993). The development of a review process for these activities would help ensure that shorebirds are considered as part of the permitting process.

## Utility Lines and Wind Turbines

*Assess impacts associated with placement of new utility towers and lines* - New towers and utility lines should not be placed in known or suspected flight corridors or near wetland areas used by shorebirds. New lines should be placed below ground if possible. In areas where placement of towers and lines have been proposed, an effort should be made to determine whether flight corridors or wetlands occur nearby so that more appropriate alternate strategies may be developed and implemented.

*Mark existing utility lines to make them more visible* - Where possible, existing utility lines should be marked or treated to make them more detectable by birds in areas where collisions involving shorebirds have occurred or are likely to occur. Techniques include: coating or painting wires, marking wires with mobile (i.e., non-stationary) spirals or strips of fiberglass or plastic, warning lights, and placement of predator silhouettes or acoustical devices to scare birds (Bevanger 1994). Recent research indicates that static wire-marking may effectively reduce the number of collisions birds have with power lines (Janss and Ferrer 1998); the wire markings used in that study included white spirals (30 cm diameter x 100 cm length) looped around the static wire and black crossed bands (two 35 cm bands attached side-by-side at their mid point) on conductors. Similarly, collision mortality (of cranes and waterfowl) was reduced in sections of transmission and distribution lines marked with dampers (112-125 cm [1.27 cm diameter] polyvinyl chloride plastic lengths twisted around the transmission lines and placed at 3.3 m intervals on the uppermost static wire) or plates (30.5 x 30.5 cm yellow fibreglass squares with a contrasting black diagonal stripe 5 cm in width and placed at 23-32 m intervals on static wires or center conductors)(Brown and Drewien 1995). Also, yellow marking devices may be more visible to birds and should be used in areas characterized by dark or cloudy conditions, whereas a combination of colors (red markers may be best in bright sunlight) would suffice for variable conditions (Raevel and Tombal 1991, Brown and Drewien 1995).

Some strategies may be more effective for certain species groups than others due to species differences in sound or color perception. Research should be conducted to evaluate the effectiveness of these and other techniques designed to reduce collisions (Bevanger 1994, English 1996). Evaluations of potential techniques should consider the type of behavior that places birds at risk. For example, the first 3 approaches listed above may be less effective in areas where shorebirds make significant nocturnal flights between foraging and roosting locations.

Other strategies to reduce the incidence of bird collisions with utility lines involve line configuration. Grouping multiple lines might make them more visible to birds, and the lines will occupy a smaller area of flight space, thus reducing the likelihood of collisions Bevanger (1994). In addition, the lines should be arranged side by side rather than in a vertical stacked formation (Bevanger 1994).

*Assess impacts associated with placement of wind turbines* - Wind turbines should not be placed in known or suspected flight corridors, near known concentrations of birds, or near wetland areas used by shorebirds. In areas where wind turbine placement has been proposed, an effort should be made to determine whether flight corridors, important wetlands, or other habitats occur nearby so that alternate strategies may be used.

## Oil Spills

*In the event of an oil spill, limit public access to beach or estuarine spill sites* - Oiled birds typically spend a considerable amount of time attempting to clean their plumage and spend less time foraging (Burger 1997). This results in an increase in energetic costs. Consequently, the impacts of an oil spill can be exacerbated by disturbances caused by human recreation (e.g., beach walking), except in some circumstances where intentional disturbance is used to exclude shorebirds and other wildlife from oiled beaches. For this reason, public access to the vicinity of spill sites or areas where oiled birds occur should be limited as much as necessary or possible until shorebird roosting, foraging, and preening behavior returns to a baseline level.

*Assess and enhance navigational assistance procedures for commercial marine vessels* - An assessment of the causes of oil spills should be conducted to determine how navigational aids might reduce the incidence of these events. Although determining the specific enhancements is beyond the scope of this document, they might include better navigational charts or training, and increased tug boat availability to assist larger vessels that enter Strait of Juan de Fuca and Puget Sound waters.

*Continue the development and refinement of oil trajectory models* - A number of oil trajectory models have been developed for spill response management. These models typically incorporate factors such as characteristics of the oil; wave action and other physical processes; and oceanographic and meteorological factors such as tidal cycle, currents and weather (ASCE Task Committee 1996, Galt 1994, Galt et al. 1996). These models are used to respond to actual spills and to identify high risk sites (Begg et al. 1997). Because of the complex functioning of currents and tides within the Puget Sound region, however, researchers are attempting to develop new models to improve site protection and spill response. These important efforts should be continued and supported (Begg et al. 1997).

*Develop baseline information needed to assess impacts of oil spills* - Baseline information on shorebird abundance and habitat use is lacking for a number of species and should be updated periodically for all potentially vulnerable species. This information will be important for efforts to: 1) assess impacts of oil spills (Parsons 1996), 2) develop appropriate remediation for spill damages (Parsons 1996), and 3) improve protection and response strategies (Begg et al. 1997).

## Plastics in the Marine Environment

*Develop procedures for controlling spills of plastics into the marine environment* - Small plastic particles injure surface feeding marine birds that intentionally or inadvertently ingest them. A strategy to control the amount of plastic that enters the marine environment will be complex because plastic waste originates from land and at-sea sources, it is virtually impossible to identify the origin of most debris (Ribic et al. 1997), and compliance is difficult to enforce (offenders are rarely caught; Laska 1997, Sutinen 1997). Local waste management programs are generally ineffective because the mobility of plastic makes this form of pollution a global management issue (Ninaber 1997).

Much of the land-based plastic pollution appears to enter the marine environment from storm water runoff. Moreover, plastic pellets are transported to marine waters from locations at any sector of the plastics industry (Redford et al. 1997), indicating that better containment is needed in all phases of pellet manufacture, packaging, transport, and use. Strategies to limit land-based sources of marine debris should involve development and implementation of regulatory and administrative measures, use of education to identify problems and solutions, creation of solid waste management infrastructure, use of new technologies, political commitment, and assessment and monitoring programs (Redford et al. 1997).

*Support changes to marine pollution regulations that result in global control of marine plastic pollution.* Annex V of the International Convention for the Protection of Pollution from Ships, known as MARPOL (73/78), was enacted in 1988 to reduce at-sea marine pollution. MARPOL is a product of the International Maritime Organization. Some authorities believe the provisions of MARPOL must be enhanced to be truly effective (Ninaber 1997). Improvements to MARPOL and other marine pollution regulations are needed and should consist of the following elements at the very least: 1) technological innovations that reduce the amount of plastic materials used on ships or that allow for at-sea processing, 2) organizational and operational changes within the shipping and marine recreation industries to facilitate policy development that addresses waste management, 3) educational communication that is designed to promote an environmental ethic and which targets specific marine ‘user’ groups, 4) government and private regulation and enforcement efforts that require development of waste management plans for ocean-going vessels and that extend authority to state or municipal authorities to levy fines for illegal dumping, and 5) creation of economic incentives by promoting development and use of recyclable products and development of on-board waste-processing equipment (Laska 1997). Finally, because waste management in the marine environment is a global issue, a standardized approach that facilitates participation by vessels and ports world-wide is needed. Incompatible vessel and port waste management programs (e.g. removal and handling of recyclable waste) will result in failure to control marine plastic pollution. For additional recommendations regarding plastic particle pollution, see Koss (1997), Laska (1997), Liffmann et al. (1997), Ninaber (1997), Sutinen (1997), and Wallace (1997).

## Pesticides and Other Chemicals

*Use extreme caution when applying chemicals near habitats used by shorebirds* - Some pesticides (including insecticides, fungicides, rodenticides, herbicides) and fertilizers (including animal waste) can directly kill fish and wildlife and indirectly affect habitat quality when used inappropriately. Because information on the toxicity and effects of specific chemical treatments to fish and wildlife is scarce or lacking for many chemical compounds, a conservative approach to chemical treatments is recommended and alternatives to chemical use are encouraged (Odum 1987). Appendix A (of this volume) lists contacts useful in assessing pesticides, herbicides, and their alternatives.

*Use current information to establish buffer zones when applying chemicals* - Buffer zones should be implemented around shorebird and waterfowl nesting habitat in agricultural landscapes to minimize the impacts of spray drift (e.g., Payne et al. 1988), particularly when the effects of drift are negative or unknown. These buffer zones should be specific to the types of chemicals used and their methods of application. Creation of adequate buffer zones requires up-to-date information about the potentially adverse effects of various compounds on estuarine and wetland ecosystems and the wildlife that use these habitats.

*Promote public education about chemical use and wetland functions through natural-resource agencies, local governments, conservation groups, and others* - There is a need for a general understanding by the public that actions near or within wetlands affect the proper functioning of the ecosystem (Grue et al. 1986). Efforts to provide important information to the public will likely require elements of research, monitoring, and education. Implementation of an integrated training and certification program for landowners and commercial pesticide applicators has been recommended as a means to provide pesticide users with important biological information and training (Grue et al. 1989).

## Human Disturbance

*Control public access and human activities in areas important to shorebirds* - This may consist of directing foot traffic away from roosting or foraging sites that should not be disturbed by human visitors. Similar efforts to control areas open to the public at Grays Harbor during spring migration appear to have been successful although an ecological assessment of human disturbance on shorebirds there has not been done. Similarly, Pfister et al. (1992) recommended identifying important beach areas and establishing vehicle restriction zones during critical roosting periods to reduce disturbance to shorebirds.

*Develop site-specific strategies to manage human disturbance* - Important wintering and migratory staging sites should be identified so that site-specific strategies can be developed, as necessary, to manage human disturbance. Potential strategies include developing informational signs that identify or describe important foraging or roosting areas. Groups of volunteers ("beach patrols") at the Dee estuary in Europe have successfully educated the public about shorebird ecology by distributing leaflets and leading organized birdwatching trips to roost sites (Kirby et al. 1993). It may be possible to coordinate similar groups of volunteers in Washington if future site disturbance warrants such action.

*Post informational signs to reduce human disturbance* - Informing the public about the sensitivity of large concentrations of roosting or foraging birds may reduce disturbance at such sites. One means to accomplish this would be to post informational signs at beach access points, public boat launches, or other marine access points.

*Address the effects of disturbance in refuge management plans* - Management plans for existing or proposed refuge or wildlife management areas should address the potential impacts of hunting and other human disturbances. Fox and Madsen (1997) assert that many refuge/wildlife management areas are linear in shape and as a consequence have few disturbance-free areas. They propose that refuges should be designed to provide disturbance-free areas and adequate buffer zones, and that refuge design must take into account the ecology of the species expected to use the area. For shorebirds, this means identifying important foraging and roosting areas and accounting for typical spatial and temporal patterns of use. For example, it would be important to determine whether shorebirds exhibited differential use of diurnal and nocturnal roost sites, and whether there was age-, sex- or species-related segregation in habitat use (Meltofte et al. 1994). In addition, it has been recommended that complexes of disturbance-free roosting sites should be situated such that the distance among roosts is equal to normal intra-roost flight distances of the species that typically move the shortest distances within a single estuary (Rehfisch et al. 1996). Obviously, a substantial amount of information is need to examine the issue of disturbance and to develop scientifically-based management guidelines as needed (Hill et al. 1997).

*Assess the level of unintentional shorebird mortality due to hunting* - The level of unintentional mortality of shorebirds due to hunting is likely very low. An evaluation of this source of mortality would provide an indication as to whether a new identification/information guide for shorebirds should be developed for inclusion in a waterfowl hunting pamphlet. Such an assessment may allow for more effective refuge design or area access considerations.

*Implement educational programs that inform the public about the ecology and behavior of shorebirds through natural-resource agencies, local governments, conservation groups, and others* - This may reduce harassment of shorebirds in areas of high use by humans (Kirby et al. 1993). In addition, public education programs should emphasize the international scope of shorebird conservation (Bucher 1995, Finney 1995); such an effort should greatly improve conservation efforts throughout the western hemisphere (Castro 1993). Finally, resource management agencies and wildlife interest groups must work together to improve regional involvement in international conservation efforts. Such efforts require improved information on the basic ecology of flyway species, identification of significant threats or potential impacts, and development of real conservation measures (Davidson et al. 1995).

## Control of Exotic Species

*Continue efforts to control the establishment and growth of cordgrass, purple loosestrife, and other noxious weeds*- A substantial effort is underway to implement an integrated weed management program in Puget Sound and Willapa Bay following guidelines set forth in an environmental impact statement on noxious emergent plant control (Washington Department of Agriculture et al. 1993). Potential methods to eradicate noxious weeds include biological control, repeated mowing, hand pulling of seedlings, and chemical treatment (Washington Department of Agriculture et al. 1993). Some of these methods are currently being used (Kilbride et al. 1995, Washington Department of Fish and Wildlife 1995c). A monitoring and assessment strategy is essential to determine the efficacy of the methods and to safeguard against unanticipated impacts (e.g., those resulting from chemical application). Appendix A lists contacts useful when assessing herbicides and their alternatives.

*Develop guidelines or regulations to control the transport of exotic invertebrates in marine waters* - A large number of exotic invertebrate species are transported in ship ballast and discharged in estuarine or portside waters around the world (Carlton 1985). Ballast occasionally is discharged in 'technically restricted places" if it is felt that petroleum products are not contained in the ballast (Carlton 1985), making current controls on ballast uptake and discharge limited or ineffective. Due to the potentially deleterious effects of exotic marine invertebrates on native marine assemblages and the apparent lack of meaningful controls on ballast management, policy makers and resource management agencies should work with marine transport organizations to develop meaningful procedures for uptake and discharge of ballast.

## Restoration/Creation of Habitat

The restoration or creation of tidal and nontidal areas for overwintering shorebirds is a possible means to mitigate environmental impacts. There is potential risk associated with this approach, however, because shorebirds do not settle in their winter quarters in a random manner, but rather return to areas used in previous years. Little information is available to assess the potential effectiveness of such restoration efforts (Wilcox 1986, Rehfisch 1994), and it is stressed that restoration is not an adequate substitute for safeguarding existing wetlands. Mitigation efforts at wintering grounds must recognize that habitat loss will most likely result in density-dependent competition at other sites in the region (see below).

Restoration of habitats used during breeding and migration seasons is also an important consideration. Substantial efforts are currently underway in the intermountain west to manage and restore wetland habitats (Inter-mountain West Joint Venture; Ratti and Kadlec 1992). These efforts should be supported.

There are many risks, often unforeseen, associated with restoration/creation projects. For example, restoration projects that reduce shore width typically result in the covering of adjacent high-level sandy tide flats with fine silt (Hill and Randerson 1986); the resulting change in substrate may not support species that formerly used the site (Burton et al. 1996).

*Develop site-specific strategies for restoration projects* - Information on local water, soil, and vegetation conditions and requirements (freshwater environments; Hammer 1997) or tidal, wind pattern, sea swell, and substrate conditions (marine environments; see below) needs to be incorporated.

*Create new sites at least five years prior to modification of natural habitat* - Artificially created sites should provide for all displaced birds and should address this need at least 5 years prior to the modification of natural habitat to allow an assessment of its success (Davidson and Evans 1987). Specifically, this 5-year period is needed to: 1) identify suitable sites; 2) acquire, design, and construct the mitigation features at sites; 3) allow settlement and stabilization of suitable sediments; and 4) allow colonization of sufficient densities of invertebrate prey species (Davidson and Evans 1987).

*Address population dynamics at long-term and regional scales through mitigation* - Mitigation studies should model population dynamics in a variety of local habitats over wide spatial (e.g. coastal, Puget Sound, and interior) and temporal (e.g., at least 5 years) scales. This is important because 1) shorebirds may use a variety of habitats (e.g., intertidal mudflats, beach, salt marsh) in an area (Burger et al. 1997); 2) changes in shorebird populations at a site during the nonbreeding season may also reflect responses to factors at other sites within the estuary, at other estuaries, or even at breeding areas (Goss-Custard and Durell 1990, Goss-Custard and Yates 1992); and 3) impacts to a site may influence shorebird populations at other sites.

*Evaluate shorebird use of artificial impoundments* - Artificially created sites may be very important to shorebirds, particularly in the Columbia Basin. Artificial drawdown sites may provide more nesting opportunities for certain species depending on the type of shoreline or the availability of nesting substrate (Paton and Bachman 1996). Care must be taken, however, to determine whether the spatial extent of the shoreline area created by the drawdown concentrates predator search effort and leads to high predation rates (Rönkä and Koivula 1997). In addition, efforts to modify such sites should be evaluated in the same manner as undisturbed sites (Warnock and Takekawa 1995).

*Create adequate roost sites* - Roost sites are an important habitat resource used by shorebirds during the nonbreeding season. Although most shorebirds appear to prefer salt marshes and beaches as roost sites, they also use dredge-spoil islands and other human-created areas. Shorebirds will likely use artificial sites if they are properly designed. A primary consideration in creating a roost site is that it must be designed to address the needs of the species that will use the site. Island roosts should provide shelter from strong winds or sea swell if these are significant environmental conditions in the particular area (Burton et al. 1996). In addition, Burton et al. (1996) recommended that island roosts should be open, with flat tops and gently sloping sides so that the birds can effectively scan for predators (Metcalfe 1984).

*Manage artificial (freshwater) sites for breeding season use* - Shorebirds will nest in artificial wetlands and impoundment drawdowns when certain conditions are met (Green 1988, Paton and Bachman 1996). The first consideration required when managing habitats for breeding birds is to determine the focal species that will use the site. Nesting requirements are quite different for species like the killdeer and American avocet. Other considerations include the depth of water in impoundments and the availability of invertebrate prey (see sections below).

*Manage artificial (freshwater) sites during fall migration* - During fall migration, shorebirds are attracted to drawdowns in reservoirs and other artificial impoundments, flooded agricultural lands, and artificial fish ponds (Rundle and Fredrickson 1981, Hands et al. 1991, Smith et al. 1991). Gradual draw-downs in impoundments are recommended because this more effectively facilitates the extended-use period of shorebirds during fall migration and assures availability of resource alternatives as local conditions change (Rundle and Fredrickson 1981, Skagen and Knopf 1994). Rundle and Fredrickson (1981) further recommended that shallow [0-5 cm (0-2 in) deep] flood pools be interspersed with exposed saturated soils to enhance shorebird use; shorebirds also used areas disked prior to flooding. It is important to maintain drawdown and flooded lands habitat for the duration of fall migration to provide habitat conditions favorable for late-season movements of juveniles (Morrison 1984, Hands et al. 1991). Shorebirds are attracted to these artificially created areas during spring migration, but seem to use them less than during fall (Rundle and Fredrickson 1981, Hands et al. 1991), although data from sites in the Pacific Northwest are lacking.

*Maximize invertebrate production at artificial (freshwater) sites* - Artificial impoundments will be most effective if the site contains features that maximize invertebrate production and foraging efficiency by shorebirds (Rehfisch 1994). The enhancement or creation of artificial sites will require local knowledge of the potential for a specific site to support desired populations of invertebrates. Some recommendations for the management of artificial impoundments are provided in Table 2.

Table 2. Features of pastures, fields, and artificial impoundments that maximize benefits for nesting or migrating shorebirds.

| Site feature | Recommended condition or action | References |
|---|---|---|
| Water depth | • Less than 5 cm (2 in) for sandpipers.<br>• Less than 10-15 cm (4-6 in) for larger species (e.g., yellowlegs, avocets). Areas of slightly deeper water may be suitable for phalaropes. | Hands et al. (1991) and Rundle and Fredrickson (1981) |
| | • Particularly at sites with a permanent or long-term management emphasis, areas of deeper water [>30 cm (12 in)] should be maintained in the center of impoundments to minimize winter mortality of invertebrates. Also, the deeper area(s) should not be allowed to dry out and would thus act as a source from which invertebrates might colonize areas flooded during migration periods. | Rehfisch (1994) |
| Seasonal availability | • Impoundments and managed drawdowns may be most important during autumn migration. Where possible, maintain a number of units (e.g., 6) during peak periods of anticipated use to ensure the availability of suitable conditions; the most important period in eastern Washington is probably August-September. | Hands et al. (1991) |
| | • Gradual drawdowns create suitable conditions over a longer time period. | Rundle and Fredrickson (1981) |
| Vegetation | • In impoundments generated by spring precipitation or runoff, greater water depths may be needed to inhibit growth of undesirable aquatic vegetation. Short drying periods may also be required to control invasive plant species. | Rundle and Fredrickson (1981) and Rehfisch (1994) |
| | • Dense shoreline vegetation may impede use by shorebirds. | Rundle and Fredrickson (1981) |
| | • Use of pastures by small and medium-sized shorebirds increases when vegetation is <20 cm (8 in) tall; shorebirds appear to prefer sites with vegetation <10 cm (4 in) tall. | Colwell and Dodd (1997) |

| | | | |
|---|---|---|---|
| Special methods of site preparation | • | Disking prior to flooding may improve site conditions. | Rundle and Fredrickson (1981) |
| Arrangement of units | • | Where possible, maintain a number of sites (e.g., 6) during peak periods of anticipated use to ensure the availability of suitable conditions. | Hands et al. (1991) and Reid et al. (1983) |
| | • | Create mosaic of shallow water areas interspersed with areas of exposed, saturated soil. | Rundle and Fredrickson (1981) |

*Maintain agricultural areas and pasturelands near sites used by shorebirds* - Colwell and Dodd (1995, 1997) recommended that a mosaic of pasture lands with various vegetation heights and flooding conditions be maintained in coastal areas near estuaries. They felt that it might be possible to manage for appropriate vegetation height through cattle grazing. They added, however, that the information needed to make specific recommendations about grazing intensity and timing was not currently available. Similarly, Rottenborn (1996) stated that the greatest use by shorebirds of agricultural lands in Virginia was in areas of flooded, bare (plowed) earth. He believed that the potential value of staging areas might be enhanced by managing adjacent pasture and agricultural lands for the open conditions most often used by shorebirds. Prescribed fire may be a potential method to create or enhance shorebird habitat in certain upland areas (Stone 1994).

*Effectively manage artificial sites* - There are several additional practical issues that should be addressed by those interested in creating or maintaining artificial habitats (Engilis and Reid 1996). First, in areas where flooding or erosion are important issues, it will be necessary to design and use spillways properly to prevent damage. Second, exotic species such as carp and purple loosestrife must be controlled and their potential reinvasion routes managed to prevent the reestablishment of these species. Third, in areas with a controlled water source it is important to maintain water flow, provide adequate draining, and use adequate spacing between inflow and outflow points to minimize stagnant water and reduce the likelihood of outbreaks of avian cholera and botulism Type C (Kadlec and Smith 1989). Fourth, an assessment of soil conditions is necessary to determine whether the site will effectively hold water (e.g., prevention of drainage to the water table, or seepage through dikes). The capacity of a site to contain water may be accomplished with as little as 10% clay content although 30% clay content is more desirable (Engilis and Reid 1996). Finally, artificially constructed islands designed as shorebird nest sites must have a gently sloping shoreline (a minimum 5:1 ratio to a height 30-60 cm above water level is recommended; Engilis and Reid 1996) and be large enough to enable shorebirds to effectively use predator avoidance behavior to protect eggs or fledglings. Resource managers should consult Engilis and Reid (1996) and Hammer (1997) for more details about wetland habitats and restoration.

*Consider other recommendations* - Evans (1991) made a number of additional recommendations that should be considered in any restoration or mitigation project. These recommendations are based on shorebird ecological studies and do not reflect results of actual mitigation assessments, which are largely lacking. First, many wintering shorebirds forage in protected areas during periods of strong winds. In areas where strong winds are known to occur, it may be important to provide sheltered, yet open feeding areas. This might be accomplished by excavating channels through mitigation tideflats. Second, it may be possible to increase the availability of invertebrate prey at wintering sites by discharging clean cooling water from industrial processes. Evans

(1991) suggests that increases in prey availability may occur if such discharges increase water and mud temperatures. However, it is recommended that such action be done experimentally and evaluated for its potential impacts to plankton and invertebrate communities prior to more widespread use. Finally, creation of adjacent wetlands may be beneficial in some situations where reclamation eliminates habitat and effectively reduces the amount of time that shorebirds can spend foraging at a site. This may be particularly important for smaller shorebirds that face a competitive disadvantage to larger species for spatially or temporally limited resources (Davidson and Evans 1986). [Shorbird conservation planning documents were prepared after this PHS document was completed; see Brown et al. (2000) and Drut and Buchanan (2000)].

## Conservation Planning

*Develop a comprehensive planning process within state and federal natural resource agencies* - Managing for shorebird populations in Washington requires development of comprehensive conservation objectives for the various shorebird species and the habitats they use. This must be done in the context of a landscape scale that incorporates the full range of species occurrences and community interactions in the habitats involved (Skagen 1997). Accomplishing this will likely facilitate more effective implementation of the recommendations described above and will likely provide greater opportunities to address the conservation needs of other species associated with the habitats used by shorebirds (Dickson and McKeating 1993, Laubhan and Fredrickson 1993, Streeter et al. 1993, Fredrickson and Laubhan 1994) [Shorbird conservation planning documents were prepared after this PHS document was completed; see Brown et al. (2000) and Drut and Buchanan (2000)].

*Broaden the geopolitical scale of conservation planning* - Due to the migratory status of most shorebirds and the potential difficulties associated with their management as described above, there is a need for comprehensive conservation planning at the flyway level. Strong partnerships and governmental commitments developed at this geopolitical scale may result in:

1) better understanding of limiting factors and population health of various species, 2) more effective management of refuges and other important areas used by shorebirds, and 3) opportunities to efficiently protect shorebirds and a large number of other species through the development of regional or flyway-level plans that emphasize specific needs and solutions. The current effort to develop a National Shorebird Conservation Plan may address these issues and should be supported. In addition, as part of a comprehensive planning and coordination process, cooperative agreements should be established whereby listing a species as threatened or endangered in a flyway state or province would prompt other flyway states or provinces to evaluate that species' status. The evaluation would determine 1) whether factors in the other states or provinces may have influenced the initial listing or are significant for recovery planning, and 2) whether the species should be listed in other states or on a flyway basis. This second concept requires that regional or flyway standards for listing be developed.

## RESEARCH NEEDS

Many authors have commented on the importance of research for conserving wildlife resources (Bildstein et al. 1991, Morrison 1991). Essential research should investigate shorebird distribution, population trends, and annual survival or mortality estimates, as well as energetic and eco-physiological relationships. In addition, shorebird ecology and habitat relationships in Washington need to be studied, including threats to shorebird habitats and their use of artificial wetlands. Research on environmental contaminants and shorebird toxicology is needed in Washington (Morrison 1991). Additional research needs are presented below. Many of these and other research topics have not been addressed for shorebird species in Washington **(**Table 3**)**.

*Evaluate the potential impacts of commercial shellfish management may have on shorebird populations* - There is currently a dearth of information on the response of shorebirds to management of bivalves in intertidal areas in the Pacific Northwest. Due to this lack of information, research should be conducted to evaluate whether various aspects of commercial bivalve production influence site quality for shorebirds.

*Determine the relationship between livestock grazing and shorebird habitat quality* - Information on the effects livestock trampling may have on shorebirds is needed for the intermountain west. Negative effects noted elsewhere include eggs or nest destruction (Rohwer et al. 1979, Guldemond et al. 1993), nest abandonment (Delehanty and Oring 1993), and adult birds spending an increased time away from their nests (Graul 1975), which likely results in increased exposure of eggs. Vegetation control is one potential positive effect. An effort is needed to identify these relationships, particularly in the Columbia Basin, and determine the conditions under which grazing activities and shorebird habitat management might be compatible.

*Develop a better understanding of the ecology and population status of the common snipe* - The common snipe is a state game species. The effects of hunting mortality on common snipe populations need to be investigated to ensure appropriate management.

*Evaluate the effects of various types of human disturbance on shorebirds* - Studies have shown that many types of human activities disturb shorebirds. Research on disturbance effects should focus on 1) vehicle and pedestrian traffic on beaches, 2) watercraft disturbance on lakes and bays, and 3) tourist/birdwatcher disturbance at migratory stopover sites.

*Determine the effects of water salinization on shorebirds and other wildlife* - The relationship between increasing water salinization within the Columbia Basin and the shorebirds that migrate through or nest in that region needs to be investigated. Understanding this relationship will be required to better control the potentially harmful effects of increasing salinization on shorebirds and other wildlife, and for effective management of vegetation.

*Use new technology to improve our understanding of shorebird ecology* - Satellite imagery has been used to assess habitat suitability and availability (Yates et al. 1993a,b), as well as to predict presence or abundance of birds (Lavers and Haines-Young 1997). Development of this and other tools, including Geographic Information Systems, should greatly increase our ability to address management issues of concern.

Table 3. Summary of research and information gaps relating to shorebird species in Washington that are addressed in this document. Solid symbols (!) represent areas of information developed from Washington, hollow symbols (") represent areas of information from elsewhere within the species range that is pertinent to Washington.

| Species | Important sites identified[a] | Population trends monitored | Food habits[b] | Physiology /mortality factors | Recent contaminant studies[c] | Effects of disturbance[d] | Effects of habitat degradation | References[e] |
|---|---|---|---|---|---|---|---|---|
| Black-bellied plover | ! | | | | ! | " | " | 7,8,9,15,16 |
| American golden-plover | ! | | | | | | | 14 |
| Pacific golden-plover | ! | | | | | | | 14 |
| Semipalmated plover | ! | | | | | " | | 14 |
| Killdeer | ! | | | | | " | | 9,14 |
| Black oyster-catcher | ! | | ! | | | " | | 11,13,17 |
| Black-necked stilt | ! | | | | | " | | 14 |
| *American avocet* | ! | | | | | | | 14 |
| Greater yellow-legs | ! | | | | | " | | 3,7,9 |
| Lesser yellowlegs | | | | | | " | | |
| Solitary sandpiper | | | | | | | | |
| Wandering tattler | | | | | | | " | 1 |
| Spotted sand-piper | | | | | | | " | 1 |
| Whimbrel | | | | | | | " | 1 |
| Marbled godwit | ! | | | | | | | 14 |
| Ruddy turnstone | | | | | | | " | 1 |

| Species | Important sites identified[a] | Population trends monitored | Food habits[b] | Physiology /mortality factors | Recent contaminant studies[c] | Effects of disturbance[d] | Effects of habitat degradation | References[e] |
|---|---|---|---|---|---|---|---|---|
| Black turnstone | | | | | | | " | 1 |
| Surfbird | | | | | | | | |
| Red knot | ! | | | | | " | | 14 |
| Sanderling | ! | | | | ! | " | | 4,15 |
| Western sandpiper | ! | | | | ! | " | | 7,9,15 |
| Least sandpiper | | | | | | " | | |
| Baird's sandpiper | | | | | | | | |
| Pectoral sandpiper | ! | | | | | | | 5 |
| Rock sandpiper | | ! | | | | | | 6,14 |
| Dunlin | ! | | ! | | ! | " | | 2,4,9,15 |
| Short-billed dowitcher | ! | | | | | " | | 7,10,14 |
| Long-billed dowitcher | ! | | | | | | | 7,10,14 |
| Common snipe | ! | | | | | | | 14 |
| Wilson's phalarope | ! | | | | | | | 14 |
| Red-necked phalarope | ! | | ! | | | | | 14,12 |
| Red phalarope | ! | | | | | | | 14 |

[a]Various species that migrate through eastern Washington use habitats whose availability is seasonally or annually unpredictable due to changes in water levels; important habitats for many species (for example, lesser yellowlegs, solitary sandpiper, spotted sandpiper, and least sandpiper) can likely be predicted seasonally or annually based on availability of suitable conditions.

[b]Only the food habits studies conducted in Washington, Oregon, or southern British Columbia are included because of substantial regional differences in energetic demands, prey availability, and prey use.

[c]Includes chemical, industrial, heavy metal, plastic, and oil pollution.

[d]See table 4 for details and references.

[e]References are as follows: 1 = Bradley and Bradley 1993, 2 = Brennan et al. 1990, 3 = Buchanan 1988, 4 = Buchanan 1992, 5 = Buchanan (in prep - a), 6 = Buchanan (in prep - b), 7 = Buchanan and Evenson 1997, 8 = Custer and Myers 1990, 9 = Evenson and Buchanan 1995, 10 = Evenson and Buchanan 1997, 11 = Frank 1982, 12 = Jehl 1986, 13 = Nysewander 1977, 14 = Paulson 1993, 15 = Schick et al. 1987, 16 = Sutherland and Goss-Custard 1991, 17 = Vermeer et al. 1989.

Table 4. Summary of responses by shorebirds to human disturbances.

| Species | Response behavior and type of disturbance | Reference |
|---|---|---|
| Killdeer | • Moved to areas beyond 60 m (197 ft) from trail[1] when visitation level exceeded 301-450 visitors/4 hr time period. Did not appear to be as sensitive to vehicle traffic. | Klein et al. (1995) |
| Black-bellied plover | • Generally found far [81-100 m (266-328 ft)] from roads, and moved to areas beyond 100 m (328 ft) when traffic level exceeded 601-750 vehicles/4 hr time period.<br>• In northern Europe, mean flush distance in response to people walking on tidal flats was 124 m (407 ft). | Klein et al. (1995)<br>Smit and Visser (1993) |
| Semipalmated plover | • Generally found far [61-80 m (200-262 ft)] from roads, and moved to areas beyond 80 m (262 ft) when traffic level exceeded 451-600 vehicles/4 hr time period.<br>• In northern Europe, the mean flush distance in response to people walking on tide flats by the closely related ringed plover (*Charadrius semipalmatus*) was 121 m (397 ft). | Klein et al. (1995)<br>Smit and Visser (1993) |
| Willet | • Generally found far [61-80 m (200-262 ft)] from roads, and moved to areas beyond 80 m (262 ft) when traffic level exceeded 451-600 vehicles/4 hr time period. Moved to areas beyond 40 m (131 ft) from trail when visitation level exceeded 151-300 visitors/4 hr time period. | Klein et al. (1995) |
| Sanderling | • Generally found far [61-80 m (200-262 ft)] from roads, and moved to areas beyond 80 m (262 ft) when traffic level exceeded 451-600 vehicles/4 hr time period. Moved to areas beyond 60 m (197 ft) from trail when visitation level exceeded 301-451 visitors/4 hr time period.<br>• Median flush response distance on a New England beach was 12 m (39 ft).<br>• More sensitive to disturbance (humans, dogs, etc.) on beaches at dusk [flush response distance = 8.3 m (27.2 ft)] than during day [flush response distance = 5.0 m (16.4)].<br>• Concentrated on sections of beach with fewer people.<br>• At high disturbance levels (vehicle count >100/day), used back beach much more than front beach, compared to periods of lower disturbance (vehicle count <20/day). | Klein et al. (1995)<br>Roberts and Evans (1993)<br>Burger and Gochfeld (1991)<br>Pfister et al. (1992) |
| Dunlin | • Generally found far [81-100 m (266-328 ft)] from roads, and moved to areas beyond 100 m (328 ft) when traffic level exceeded 301-450 vehicles/4 hr time period.<br>• In northern Europe, mean flush distance in response to people walking on tidal flats was 71-163 m (233-535 ft). | Klein et al. (1995)<br>Smit and Visser (1993) |
| Western/least sandpiper | • Generally found far [61-80 m (200-262 ft)] from roads, and moved to areas beyond 80 m (262 ft) when traffic level exceeded 451-600 vehicles/4 hr time period. | Klein et al. (1995) |
| Greater yellowlegs | • Did not respond to differing levels of road traffic, but foraging areas were located further from road than expected based on distribution of habitat. Most greater yellowlegs used areas >20 m (66 ft) from the road. | Klein et al. (1995) |
| Lesser yellowlegs | • Did not respond to differing levels of road traffic, but foraging areas were located further from road than expected based on distribution of habitat. Most lesser yellowlegs used areas >20 m (66 ft) from the road. | Klein et al. (1995) |
| Red Knot | • Did not respond to differing levels of road traffic, but foraging areas were located further from road than expected based on distribution of habitat. Most red knots used areas >90 m (295 ft) from the road.<br>• In northern Europe, mean flight distance in response to person in kayak was about 250 m (820 ft)<br>• Mean flight distance in response to wind surfer was about 200 m (656 ft).<br>• In northern Europe, birds less approachable on days with aircraft activity. Incidence of restlessness greater on days with aircraft activity. | Klein et al. (1995)<br>Smit and Visser (1993)<br>Koolhaas et al. (1993) |

| Species | Response behavior and type of disturbance | Reference |
|---|---|---|
| Short-billed dowitcher | • Did not respond to differing levels of road traffic, but foraging areas were located further from road than expected based on distribution of habitat. Dowitchers were more common at >90 m (295 ft) than at any distances closer to road.<br>• Abundance on front beach declined sharply when level of disturbance exceeded 10-40 vehicles/day. | Klein et al. (1995)<br>Pfister et al. (1992) |
| Black-necked stilt | • Avoided habitats within 20 m (66 ft) of road. | Klein et al. (1995) |
| Eurasian oystercatcher (*Haematopus ostralegus*) | • In northern Europe, took to flight when walking person within 250 m (820 ft) 57% of time. In northern Africa, flocks were flushed by a walking person at 400-500 m (1,312-1,640 ft). Mean flight distance in response to walking person ranged from 85-138 m (279-453 ft).<br>• Mean flight distance in response to person in kayak was about 40 m (131 ft).<br>• Mean flight distance in response to wind surfer was about 125 m (410 ft). | Smit and Visser (1993) |
| Redshank *Tringa totanus* | • Mean flight distance in response to person in kayak was about 195 m (640 ft).<br>• Mean flight distance in response to wind surfer was about 285 m (935 ft). | Smit and Visser (1993) |
| Bar-tailed godwit | • Mean flight distance in response to person in kayak was about 200 m (656 ft).<br>• Mean flight distance in response to wind surfer was about 240 m (787 ft).<br>• Mean flight distance in response to walking person ranged from 101-219 m (331-718 ft).<br>• At least 20% of birds in flock flushed when jet flew within 400-500 m (1,312-1,640 ft).<br>• At least 55% of birds in flock flushed when helicopter flew within 900-1,000 m (2,953-3,281 ft). | Smit and Visser (1993) |
| Eurasian Curlew *Numenius arquata* | • Mean flight distance in response to person in kayak was about 230 m (755 ft).<br>• Mean flight distance in response to wind surfer was about 400 m (1,312 ft).<br>• Mean flight distance in response to walking person ranged from 101-339 m (331-1,112 ft). | Smit and Visser (1993) |
| Black turnstone | • In northern Europe, mean flush distance in response to people walking on tidal flats was 47 m (154 ft). | Smit and Visser (1993) |
| Primarily 8 species, including: semipalmated sandpiper, ruddy turnstone, sanderling, both dowitchers, red knot, dunlin, and greater yellowlegs | • In two New Jersey bays, factors influencing whether shorebirds flew but returned as a result of disturbances included duration of disturbance (short disturbances causes more flights), number of disturbances, distance between birds and source of disturbance, number of children at the site, number of people walking, and number of dogs. Factors influencing whether shorebirds flew away and did not return included duration of disturbance, the number of boats, and the number of children at the site. | Burger (1986) |

[2]Trail or road traffic in various studies refers to responses of shorebirds to pedestrian or vehicular activity on trails or roads adjacent to intertidal areas within a refuge, unless otherwise noted.

## ACKNOWLEDGMENTS

This document was improved by constructive comments provided by Dr. Robert W. Butler, Dr. Robert E. Gill, Jr., and Dr. Susan K. Skagen. Comments were provided by the following WDFW staff: Brett Dumbauld, Doug Kuehn, Greg Lippert, Hal Michael, Ruth Milner, Greg Schirato, and Mark Schuller. Dr. Nils Warnock provided advice and important reference materials.

## REFERENCES


Ainley, D. G. and T. J. Lewis. 1974. The history of Farallon Island marine bird populations, 1854-1972. Condor 76:432-446.

Alberico, J. A. R. 1993. Drought and predation cause avocet and stilt breeding failure in Nevada. Western Birds 24:43-51.

American Society of Civil Engineers. 1990. Agricultural salinity assessment and management. K. K. Tanji, editor. ASCE manuals and reports on engineering practice, Number 71.

Andres, B. A. 1997. The *Exxon Valdez* oil spill disrupted the breeding of black oystercatchers. Journal of Wildlife Management 61:1322-1328.

))))). 1998. Shoreline habitat use of black oystercatchers breeding in Prince William Sound, Alaska. Journal of Field Ornithology 69:626-634.

Atkinson, J. 1992. A preliminary investigation of benthic invertebrates associated with intertidal mud-flats and intertidal mudflats infested with *Spartina* at one location in Willapa Bay, Washington. Report to Willapa Bay National Wildlife Refuge.

ASCE Task Committee on Modeling of Oil Spills of the Water Resources Engineering Division. 1996. State-of-the-art review of modeling transport and fate of oil spills. Journal of Hydrological Engineering 122:594-609.

Avery, M., P.F. Springer, and J. F. Cassell. 1976. The effects of a tall tower on nocturnal bird migration: a portable ceilometer study. Auk 93:281-291.

Baltz, D. M., and G. V. Morejohn. 1976. Evidence from seabirds of plastic particle pollution off central California. Western Birds 7:111-112.

Begg, G. S., J. B. Reid, M. L. Tasker, and A. Webb. 1997. Assessing the vulnerability of seabirds to oil pollution: sensitivity to spatial scale. Colonial Waterbirds 20:339-352.

Bellamy, D. F., P. H. Clarke, D. M. John, D. Jones, A. Whitick, and T. Darke. 1967. Effects of pollution from the Torrey Canyon on littoral and sublittoral ecosystems. Nature 216:1170-1173.

Bent, A. C. 1927. Life histories of North American shorebirds. Part 1. U.S. National Museum Bulletin, Washington, D.C., USA.

Beukema, J. J., K. Essink, H. Michaelis, and L. Zwarts. 1993. Year-to-year variability in the biomass of macrobenthic animals on tidal flats of the Wadden Sea: how predictable is this food source for birds? Netherlands Journal of Sea Research 31:319-330.

Bevanger, K. 1994. Bird interactions with utility structures: collision and electrocution, causes and mitigating measures. Ibis 136:412-425.

Bildstein, K. L., G. T. Bancroft, P. J. Dugan, D. H. Gordon, R. M. Erwin, E. Nol, L. X. Payne, and S. E. Senner. 1991. Approaches to the conservation of coastal wetlands in the western hemisphere. Wilson Bulletin 103:218-254.

Blomqvist, S., A. Frank, and L. R. Petersson. 1987. Metals in liver and kidney tissues of autumn- migrating dunlin (*Calidris alpina*) and curlew sandpiper (*Calidris ferruginea*) staging at the Baltic Sea. Marine Ecology Program Service 35:1-13.

Bond, S. I. 1971. Red phalarope mortality in southern California. California Birds 2:97.

Boule, M., N. Olmsted, and T. Miller. 1983. Inventory of wetland resources and an evaluation of wetland management in western Washington. Washington Department of Ecology, Olympia, Washington, USA.

Bowen, B. S., and A. D. Kruse. 1993. Effects of grazing on nesting by upland sandpipers in south central North Dakota. Journal of Wildlife Management 57: 291-301.

Bowles, J. H. 1918. The Limicolae of the state of Washington. Auk 35:326-333.

Boyd, H. 1962. Mortality and fertility of European Charadrii. Ibis 104:368 -387.

Bradley, R. A., and D. W. Bradley. 1993. Wintering shorebirds increase after kelp (*Macrocystis*) recovery. Condor 95:372-376.

Brennan, L. A., J. B. Buchanan, S. G. Herman, and T. M. Johnson. 1985. Interhabitat movements of wintering dunlins in western Washington. Murrelet 66: 11-16.

))))), M. A. Finger, J. B. Buchanan, C. T. Schick, and S. G. Herman. 1990. Stomach contents of some dunlins collected in western Washington. Northwestern Naturalist 71:99-102.

Brown, S., C. Hickey and B. Harrington. 2000. United States shorebird conservation plan. Manomet Center for Conservation Sciences, Manomet, Massachusetts.

Brown, W. M., and R. C. Drewien. 1995. Evaluation of two power line markers to reduce crane and waterfowl collision and mortality. Wildlife Society Bulletin 23:217-227.

Bryant, D. M. 1979. Effects of prey density and site character on estuary usage by overwintering waders (Charadrii). Estuarine, Coastal and Marine Science 9:369-384.

Buchanan, J. B. 1988. Migration and winter populations of greater yellowlegs, *Tringa melanoleuca*, in western Washington. Canadian Field-Naturalist 102:611-616.

))))). 1992. Winter abundance of shorebirds at coastal Washington beaches. Washington Birds 2:12-19.

))))). In prep. Pectoral sandpiper. In T. R. Wahl and W. M. Tweit, editors. Birds of Washington.

))))). 1999. Recent changes in the winter distribution and abundance of rock sandpipers in North America. Western Birds 30:193-199.

))))), L. A. Brennan, C. T. Schick, S. G. Herman, and T. M. Johnson. 1986. Age and sex composition of wintering dunlin populations in western Washington. Wader Study Group Bulletin 46:31-41.

))))), and J. R. Evenson. 1997. Abundance of shorebirds at Willapa Bay, Washington. Western Birds 28:158-168.

))))), and D. Kraege. 1998. Results of a hunter survey for common snipes harvested in the winter of 1997-1998. Unpublished Report, Washington Department of Fish and Wildlife, Olympia, Washington, USA.

Bucher, E. H. 1995. Western Hemisphere Shorebird reserve network: looking to the future. Wader Study Group Bulletin 77:64-66.

Burger, J. 1997. Effects of oiling on feeding behavior of sanderlings and semipalmated plovers in New Jersey. Condor 99:290-298.

))))), and M. Gochfeld. 1991. Human activity influence and diurnal and nocturnal foraging of Sanderlings (*Calidris alba*). Condor 93:259-265.

)))))， L. Niles, and K. E. Clark. 1997. Importance of beach, mudflat, and marsh habitats to migrant shorebirds on Delaware Bay. Biological Conservation 79:283-292.

Burton, N. H. K., P. R. Evans, and M. A. Robinson. 1996. Effects on shorebird numbers of disturbance, the loss of a roost site and its replacement by an artificial island at Hartlepool, Cleveland. Biological Conservation 77:193-201.

Burton, P. J. K. 1974. Feeding and the feeding apparatus in waders. British Museum of Natural History, London, England.

Butler, R. W. 1994. Distribution and abundance of western sandpipers, dunlins, and black-bellied plovers in the Fraser River estuary. Pages 18-23 *in* R. W. Butler and K. Vermeer, editors. The abundance and distribution of estuarine birds in the Strait of Georgia, British Columbia. Canadian Wildlife Service Occasional Paper Number 83.

))))), and R. W. Campbell. 1987. The birds of the Fraser River delta: populations, ecology and international significance. Canadian Wildlife Service Occasional Paper Number 65.

))))), G. W. Kaiser, and G. E. J. Smith. 1987. Migratory chronology, length of stay, sex ratio and weight of western sandpipers (*Calidris mauri*) on the south coast of British Columbia. Journal of Field Ornithology 58:103-111.

Carlton, J. T. 1985. Transoceanic and interoceanic dispersal of coastal marine organisms: the biology of ballast water. Oceanography and Marine Biology, Annual Review 23:313-371.

))))), and J. B. Geller. 1993. Ecological roulette: the global transport of nonindigenous marine organisms. Science 261:78-82.

))))), J. K. Thompson, L. E. Schemel, and F. H. Nichols. 1990. Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam *Potamocorbula amurensis*. I. Introduction and dispersal. Marine Ecology Program Service 66:81-94.

Castro, G. 1993. Conserving migratory waterbirds - a challenge for international cooperation. Pages 120-123 *in* M. Moser, R. C. Prentice, and J. van Vessem, editors. Waterfowl and wetland conservation in the 1990s: a global perspective. International Waterfowl and Wetlands Research Bulletin, Special Publication Number 26. United Kingdom.

Chapman, B. R. 1984. Seasonal abundance and habitat-use patterns of coastal bird populations on Padre and Mustang Island barrier beaches (following the Ixtoc oil spill). U.S. Fish and Wildlife Service, FWS/OBS-83/31.

Coe, J. M. and D. B. Rogers, editors. 1997. Marine debris: sources, impacts, and solutions. Springer-Verlag, New York.

Colwell, M. A., and S. L. Dodd. 1995. Waterbird communities and habitat relationships in coastal pastures of northern California. Conservation Biology 9:827-834.

))))), and ))))). 1997. Environmental and habitat correlates of pasture use by nonbreeding shorebirds. Condor 99:337-344.

Connors, P. G., and K. G. Smith. 1982. Oceanic plastic particle pollution: suspected effect on fat deposition in red phalaropes. Marine Pollution Bulletin 13:18-20.

Cooke, W. W. 1910. Distribution and migration of North American shorebirds. United States Biological Survey Bulletin No. 35.

Cordell, J. R. 1998. Asian copepods in Pacific Northwest estuaries. Puget Sound Notes 41:1-5.

)))))), and S. M. Morrison. 1996. The invasive Asian copepod *Pseudodiaptomus inopinus* in Oregon, Washington, and British Columbia estuaries. Estuaries 16:629-638.

Crouch, G. L. 1982. Wildlife on ungrazed and grazed bottomlands on the south Platte River, northeastern Colorado. Pages 186-197 *in* J. M. Peek and P.D. Dalke, editors. Wildlife-livestock relationships symposium. University of Idaho, Moscow, Idaho, USA.

Curio, E. 1976. The ethology of predation. Springer Verlag, New York, USA.

Custer, T. W., and C. A. Mitchell. 1991. Contaminant exposure of willets feeding in agricultural drainages of the Lower Rio Grande Valley of south Texas. Environmental Monitoring and Assessment 16: 189-200.

)))))), and J. P. Myers. 1990. Organochlorines, mercury, and selenium in wintering shorebirds from Washington and California. California Fish and Game 76:118-125.

Dahl, T. E. 1990. Wetlands of the United States 1780's to 1980's. Unpublished Report, U. S. Fish and Wildlife Service, Washington, D.C., USA.

Davidson, N. C. 1981. Survival of shorebirds (Charadrii) during severe weather: the role of nutritional reserves. Pages 231 -249 *in* N. V. Jones and W. J. Wolfe, editors. Feeding and the survival strategies of estuarine organisms. Plenum Press, New York, New York, USA.

)))))), and P. R. Evans. 1982. Mortality of redshanks and oystercatchers from starvation during severe weather. Bird Study 29:183-188.

)))))), and ))))). 1986. The role and potential of man-made and man-modified wetlands in the enhancement of the survival of overwintering shorebirds. Colonial Waterbirds 9:176-188.

)))))), and ))))). 1987. Habitat restoration and creation: its role and potential in the conservation of waders. Wader Study Group Bulletin 49 (Supplemental): 139-145.

)))))), and ))))). 1989. Prebreeding accumulation of fat and muscle protein by arctic-breeding shorebirds. Proceedings of the International Ornithological Congress 19:342-352.

)))))), ))))), and J. D. Uttley. 1986a. Geographical variation of protein reserves in birds: the pectoral muscle mass of dunlins *Calidris alpina* in winter. Journal of Zoology, London (A) 208:125-133.

)))))), P. I. Rothwell, and M. W. Pienkowski. 1995. Towards a flyway conservation strategy for waders. Wader Study Group Bulletin 77:70-81.

)))))), and D. A. Stroud. 1996. Conserving international coastal habitat networks on migratory waterfowl flyways. Journal of Coastal Conservation 2:41-54.

)))))), J. D. Uttley, and P. R. Evans. 1986b. Geographic variation in the lean mass of dunlins wintering in Britain. Ardea 74:191-198.

Day, R. H., D. H. S. Wehle, and F. C. Coleman. 1985. Ingestion of plastic pollutants by marine birds. Pages 344-386 *in* R. S. Shomura and H. O. Yoshida, editors. Proceedings of the workshop on the fate and impact of marine debris. U.S. Department Committee, NOAA Technical Memo, NMFS, NOAA-TM-NMFS-SWFC-54.

Delehanty, D. A., and L. W. Oring. 1993. Effect of clutch size on incubation persistence in male Wilson's phalaropes (*Phalaropus tricolor*). Auk 110: 293-300.

DeWeese, L. R., L. C. McEwen, L. A. Settimi, and R. D. Deblinger. 1983. Effects on birds of fenthion aerial application for mosquito control. Journal of Economic Entomology 76:906-911.

Dickson, H. L., and G. McKeating. 1993. Wetland management for shorebirds and other species - experiences on the Canadian prairies. Transactions of the North American Wildlife and Natural Resources Conference 58:370-378.

Drut, M. S., and J. B. Buchanan. 2000. U.S. National shorebird conservation plan: Northern Pacific coast working group regional management plan. U.S. Fish and Wildlife Service, Portland, Oregon.

DuBowy, P. J. 1989. Effects of diet on selenium bio-accumulation in marsh birds. Journal of Wildlife Management 53:776-781.

Duffield, J. M. 1986. Waterbird use of a urban stormwater wetland system in central California, USA. Colonial Waterbirds 9:227-235.

Dugan, P. J., P. R. Evans, L. R. Goodyer, and N. C. Davidson. 1981. Winter fat reserves in shorebirds: disturbance of regulated levels by severe weather conditions. Ibis 123:359-363.

Duinker, J. C., J. P. Boon, and M. T. J. Hillebrand. 1984. Organochlorines in benthic invertebrates and sediments from the Dutch Wadden Sea: identification of individual PCB components. Netherlands Journal of Sea Research 17:19-38.

Engilis, A., Jr., and F.A. Reid. 1996. Challenges in wetland restoration of the western Great Basin. International Wader Studies 9:71-79.

English, I. 1996. Power cable casualties within the Clyde Valley. Scottish Bird News 41:10.

Erickson, W. P., G. D. Johnson, M. D. Strickland, D. P. Young Jr., K. J. Sernka, and R. E. Good. 2001. Avian collisions with wind turbines: A summary of existing studies and comparisons to other sources of avian collision mortality in the United States. National Wind Coordinationg Committee (NWCC), Washington D.C.

Esselink, P., J. van Belkum, and K. Essink. 1989. The effect of organic pollution on local distribution of *Nereis diversicolor* and *Corophium volutator*. Netherlands Journal of Sea Research 23:323-332.

Evans, P. R. 1976. Energy balance and optimal foraging strategies in shorebirds: some implications for their distributions and movements in the non-breeding season. Ardea 64:117-139.

))))). 1991. Seasonal and annual patterns of mortality in migratory shorebirds: some conservation implications. Pages 346-359 *in* C. M. Perrins, J. D. Lebreton, and G. J. M. Hirons, editors. Bird population studies: relevance to conservation and management. Oxford University Press, Oxford, United Kingdom.

)))))), and N. C. Davidson. 1990. Migration strategies of waders breeding in arctic and north temperate latitudes. Pages 387-398 *in* E. Gwinner, editor. Bird migration - physiology and ecophysiology. Springer-Verlag, Berlin, Germany.

))))), ))))), T. Piersma, and M. W. Pienkowski. 1991. Implications of habitat loss at migration staging posts for shorebird populations. Proceedings of the International Ornithological Congress 20:2228- 2235.

))))), D. M. Herdson, P. J. Knight, and M. W. Pienkowski. 1979. Short term effects of reclamation of part of Seal Sands, Teesmouth, on wintering waders and Shelduck. I. Shorebird diets, invertebrate densities, and the impact of predation on the invertebrates. Oecologia 41:183-206.

))))), and M. W. Pienkowski. 1984. Population dynamics of shorebirds. Pages 83-123 *in* J. Burger and B. L. Olla, editors. Shorebirds: breeding behavior and populations. Plenum Press, New York, New York, USA.

Evenson, J. R., and J. B. Buchanan. 1995. Winter shorebird abundance at Greater Puget Sound estuaries: recent census results and identification of potential monitoring sites. Pages 647-654 *in* E. Robichaud, editor. Puget Sound Research '95. Puget Sound Water Quality Authority, Olympia, Washington, USA.

))))), and ))))). 1997. Seasonal abundance of shorebirds at Puget Sound estuaries. Washington Birds 6:34-62.

Ferns, P. N. 1983. Sediment mobility in the Severn estuary and its influence upon the distribution of shorebirds. Canadian Journal of Fisheries and Aquatic Sciences 40 (Supplemental 1):331-340.

))))), and J. I. Anderson. 1994. Cadmium in the diet and body tissues of dunlins *Calidris alpina*, from the Bristol Channel, United Kingdom. Environmental Pollution 86:225-231.

Finney, G. 1995. Western Hemisphere Shorebird Network: looking to the future. Wader Study Group Bulletin 77:66-68.

Forbush, E. H. 1912. A history of the game birds, wildfowl, and shore birds of Massachusetts and adjacent states. Massachusetts Board of Agriculture.

Fox, A. D., and J. Madsen. 1997. Behavioral and distributional effects of hunting disturbance on waterbirds in Europe: implications for refuge design. Journal of Applied Ecology 34:1-13.

Fox, G. A., A. P. Gilman, D. B. Peakall, and F. W. Anderka. 1978. Behavioral abnormalities of nesting Lake Ontario herring gulls. Journal of Wildlife Management 42:477-483.

Frank, P. W. 1982. Effects of winter feeding on limpets by black oystercatchers, *Haematopus bachmani*. Ecology 63:1352-1362.

Fredrickson, L. H., and M. K. Laubhan. 1994. Intensive wetland management: a key to biodiversity. Transactions of North American Wildlife and Natural Resources Conference 59:555-565.

))))), and F. A. Reid. 1990. Impacts of hydrologic alteration on management of freshwater wetlands. Pages 71-90 *in* J. M. Sweeney, editor. Management of dynamic ecosystems. North Central Section, The Wildlife Society, West Lafayette, Indiana, USA.

Frenkel, R. E., and L. M. Kunze. 1984. Introduction and spread of three *Spartina* species in the Pacific Northwest. Association of American Geographers 4:22-25.

Fretwell, S. D., and H. L. Lucas. 1970. On territorial behavior and other factors influencing habitat distribution in birds. I. Theoretical development. Acta Biotheoretica. 19:16-36.

Galbraith, H. 1987. Threats to breeding waders: the impact of changing agricultural land-use on the breeding ecology of lapwings. Wader Study Group Bulletin 49(Suppl.):102-104.

Galt, J. A. 1994. Trajectory analysis for oil spills. Journal of Advanced Marine Technical Conference 11:91-126.

))))), D. L. Payton, H. Norris, and C. Friel. 1996. Digital distribution standard for NOAA trajectory analysis information. HAZMAT Report 96-4. National Oceanographic and Atmospheric Administration, Seattle, Washington, USA.

Gerritsen, A. F. C., and Y. M. van Heezik. 1985. Substrate preference and substrate related foraging behaviour in three *Calidris* species. Netherlands Journal of Zoology 35:671-692.

Gilbertson, M., and G. A. Fox. 1977. Pollutant-associated embryonic mortality of Great Lakes herring gulls. Environmental Pollution 12:211-216.

))))), R. D. Morris, and R. A. Hunter. 1976. Abnormal chicks and PCB levels in eggs of colonial birds on the lower Great Lakes (1971-73). Auk 93:434-442.

Gill, R. E., Jr., R. W. Butler, P. S. Tomkovich, T. Mundkur, and C. M. Handel. 1994. Conservation of North Pacific shorebirds. Transactions of North American Wildlife and Natural Resources Conference 59:63-78.

Goede, A. A. 1985. Mercury, selenium, arsenic and zinc in waders from the Dutch Wadden Sea. Environmental Pollution (series A) 37:287-309.

))))), and P. de Voogt. 1985. Lead and cadmium in waders from the Dutch Wadden Sea. Environmental Pollution (series A) 37:311-322.

Goerke, H., G. Elder, K. Weber, and W. Ernst. 1979. Patterns of organochlorine residues in animals of different trophic levels from the Waser estuary. Marine Pollution Bulletin 10:127-133.

Goss-Custard, J. D. 1977. The ecology of the Wash. III. Density-related behavior and the possible effects of a loss of feeding grounds on wading birds (Charadrii). Journal of Applied Ecology 14:721- 739.

))))). 1979. Effects of habitat loss on the numbers of overwintering shorebirds. Studies in Avian Biology 2:167-178.

))))). 1985. Foraging behavior of wading birds and the carrying capacity of estuaries. Pages 169-188 *in* R. M. Sibley and R. H. Smith, editors. Behavioral ecology: ecological consequences of adaptive behaviour. Blackwell, Oxford, United Kingdom.

))))), and S. E. A. le V. dit Durell. 1987. Age-related effects in oystercatchers, *Haemotopus ostralegus* feeding on mussels, *Mytilus edulis*. II. Aggression. Journal of Animal Ecology 56:537-548.

))))), and ))))). 1990. Bird behaviour and environmental planning: approaches in the study of wader populations. Ibis 132:273-289.

))))), and M. E. Moser. 1988. Rates of change in the numbers of dunlin *Calidris alpina*, wintering in British estuaries in relation to the spread of *Spartina anglica*. Journal of Applied Ecology 25:95 -109.

))))), and N. Verboven. 1993. Disturbance and feeding shorebirds on the Exe estuary. Wader Study Group Bulletin 68 (special issue):59-66.

)))))), and M. G. Yates. 1992. Towards predicting the effect of saltmarsh reclamation on feeding bird numbers on the Wash. Journal of Applied Ecology 29:330-340.

Grant, J. 1984. Sediment microtopography and shorebird foraging. Marine Ecology - Program Series 19: 293-296.

Granval, P., R. Aliaga, and P. Soto. 1993. The impact of agricultural management on earthworms (*Lumbicidae*), common snipe (*Gallinago gallinago*) and the environmental value of grasslands in the Dives marshes Calvados. Gibier faune sauvage 10:59-73.

Grassle, J. F., R. Elmoren, and J. P. Grassle. 1980. Response of benthic communities in MERL experimental ecosystems to low level, chronic additions of Number 2 fuel oil. Marine Environmental Research 4:279-297.

Graul, W. D. 1975. Breeding biology of the mountain plover. Wilson Bulletin 87:6-31.

Green, R. E. 1988. Effects of environmental factors on the timing and success of breeding common snipe *Gallinago gallinago*. Journal of Applied Ecology 25:79-93.

Grinnell, J., H.C. Bryant, and T. I. Scorer. 1918. The game birds of California. University of California Press, Berkeley.

Gromadzka, J. 1983. Results of bird-ringing in Poland: migrations of dunlin *Calidris alpina*. Acta Ornithologica Warsaw 19:113-136.

Gratto-Trevor, C. L. and H. L. Dickson. 1994. Confirmation of elliptical migration in a population of semipalmated sandpipers. Wilson Bulletin 106:78-90.

))))), V. H. Johnson, and S. T. Pepper. 1998. Changes in shorebird and eider abundance in the Rasmussen Lowlands, NWT. Wilson Bulletin 110:316-325.

Grue, C. E., L. R. DeWeese, P. Mineau, G. A. Swanson, J. R. Foster, P. M. Amold, J. N. Huckins, P. J. Sheehan, W. K. Marshall, and A. P. Ludden. 1986. Potential impacts of agricultural chemicals on waterfowl and other wildlife inhabiting prairie wetlands: an evaluation of research needs and approaches. Transactions of North American Wildlife and Natural Resources Conference 51: 357-383.

))))), M. W. Tome, T. A. Messmer, D. B. Henry, G. A. Swanson, L. R. DeWeese. 1989. Agricultural chemicals and prairie pothole wetlands: meeting the needs of the resource and the farmer-U.S. perspective. Transactions of North American Wildlife and Natural Resources Conference 54:43-57.

Guldemond, J. A., F. Parmentier, and F. Visbeen. 1993. Meadow birds, field management and nest protection in a Dutch peat soil area. Wader Study Group Bulletin 70:42-48.

Haig, S. M., C. L. Gratto-Trevor, T. D. Mullins, and M. A. Colwell. 1997. Population identification of western hemisphere shorebirds throughout the annual cycle. Molecular Ecology 6:413-427.

Hainline, J. L. 1974. The distribution, migration, and breeding of shorebirds in western Nevada. Thesis, University of Nevada, Reno, Nevada, USA.

Hallock, R. J. and L. L. Hallock. 1993. Detailed study of irrigation drainage in and near wildlife management areas, west-central Nevada, 1987-90. Part B. Effect on biota in Stillwater and Fernley Wildlife Management Areas and other nearby wetlands. U.S. Geologic Survey, Water Resources Investigations, Report Number 92-4024B.

Hammer, D. A. 1997. Creating freshwater wetlands. Second edition. CRC Press/Lewis Publishing Company, Boca Raton, Florida, USA.

Hands, H. M., M. R. Bran, and J. W. Smith. 1991. Migrant shorebird use of marsh, moist soil, and flooded agricultural habitats. Wildlife Society Bulletin 19:457-464.

Harrington, B. and E. Perry. 1995. Important shorebird staging sites meeting Western Hemisphere Shorebird Reserve Network criteria in the United States. Western Hemisphere Shorebird Reserve Network.

Helmers, D. L. 1992. Shorebird management manual. Western Hemisphere Shorebird Reserve Network, Manomet, Massachusetts, USA.

Herman, S. G., and J. B. Bulger. 1981. The distribution and abundance of shorebirds during the 1981 spring migration at Grays Harbor, Washington. U.S. Army Corps of Engineers, Contract report DACW67 -81-M-0936. Seattle, Washington, USA.

Hicklin, P. W. and P. C. Smith. 1984. Selection of foraging sites and invertebrate prey by migrant semipalmated sandpipers, *Calidris pusilla* (Pallas), in Minas Basin, Bay of Fundy. Canadian Journal of Zoology 62:2201-2210.

Hill, D., D. Hockin, D. Price, G. Tucker, R. Morris, and J. Treweek. 1997. Bird disturbance: improving the quality and utility of disturbance research. Journal of Applied Ecology 34:275-288.

Hill, M. I., and P. F. Randerson. 1986. Saltmarsh vegetation communities of the Wash and their recent development. Pages 111-122 *in* P. Doody and B. Barnett, editors. The Wash and its environment. Nature Conservancy Council, Peterborough, United Kingdom.

Hockey, P. A. R., R. A. Navarro, B. Kalejta, and C. R. Velasquez. 1992. The riddle of the sands: why are shorebird densities so high in southern estuaries? American Naturalist 140:961-979.

Howe, M. A., P. H. Geissler, and B. A. Harrington. 1989. Population trends of North American shorebirds based on the International Shorebird Survey. Biological Conservation 49:185-199.

Howell, R. 1985. The effect of bait-digging on the bioavailability of heavy metals from surficial intertidal marine sediments. Marine Pollution Bulletin 16:292-295.

Janss, G. F. E., and M. Ferrer. 1998. Rate of bird collision with power lines: effects of conductor-marking and static wire-marking. Journal of Field Ornithology 69:8-17.

Jehl, J. R., Jr. 1986. Biology of red-necked phalaropes (*Phalaropus lobatus*) at the western edge of the Great Basin in fall migration. Great Basin Naturalist 46:185-197.

Jewett, S. G., W. P. Taylor, W. T. Shaw, and J. W. Aldridge. 1953. Birds of Washington state. University of Washington Press, Seattle, Washington, USA.

Kadlec, J. A., and L. M. Smith. 1989. The Great Basin marshes. Pages 451-474 in L. M. Smith, R. L. Pederson, and R. M. Kaminski, editors. Habitat management for migrating and wintering waterfowl in North America. Texas Tech University Press, Lubbock, Texas, USA.

Kaiser, G. W., K. Fry, and J. G. Ireland. 1980. Ingestion of lead shot by dunlin. Murrelet 61:31.

Kelly, J. P., J. G. Evens, R. W. Stallcup, and D. Wimpfheimer. 1996. Effects of aquaculture on habitat use by wintering shorebirds in Tomales Bay, California. California Fish and Game 82:160-174.

Kilbride, K. M., F. L. Paveglio, and C. E. Grue. 1995. Control of smooth cordgrass with Rodeo in a southwestern Washington estuary. Wildlife Society Bulletin 23:520-524.

Kirby, J. S., C. Clee, and V. Seager. 1993. Impact and extent of recreational disturbance to wader roosts on the Dee estuary: some preliminary results. Wader Study Group Bulletin 68 (special issue):53-58.

Kitchin, E. A. 1949. Birds of the Olympic Peninsula. Olympic Stationers, Port Angeles, Washington, USA.

Klein, M. L., S. R. Humphrey, and H. F. Percival. 1995. Effects of ecotourism on distribution of waterbirds in a wildlife refuge. Conservation Biology 9:1454-1465.

Kohler, B., and G. Rauer. 1991. Grazing to improve wader habitat on alkaline meadows in eastern Austria. Wader Study Group Bulletin 61 (Supplemental):82-85.

Koolhaas, A., A. Dekinga, and T. Piersma. 1993. Disturbance of foraging knots by aircraft in the Dutch Wadden Sea in August-October 1992. Wader Study Group Bulletin 68 (special issue):20-22.

Kopenski, R. P. and E. R. Long. 1981. An environmental assessment of North Puget Sound and the Strait of Juan de Fuca: a summary. National Oceanic and Atmospheric Administration, Office of Marine Pollution Assessment, Seattle, Washington, USA.

Koss, L. J. 1997. Dealing with ship-generated plastic waste on U.S. Navy surface ships. Pages 263-270 *in* Coe, J. M. and D. B. Rogers, editors. Marine debris: sources, impacts, and solutions. Springer-Verlag, New York.

Kus, B. E., P. Ashman, G. W. Page, and L. E. Stenzel. 1984. Age-related mortality in a wintering population of dunlin. Auk 101:69-73.

Lambeck, R. H. D., A. J. J. Sandee, and L. de Wolf. 1989. Long-term patterns in the wader usage of an intertidal flat in the Oosterschelde (SW Netherlands) and the impact of the closure of an adjacent estuary. Journal of Applied Ecology 26:419-431.

Landin, M. C. 1991. Growth habits and other considerations of smooth cordgrass, *Spartina alterniflora* Loisel. Pages 15-20 *in* T. F. Mumford Jr., P. Peyton, J. R. Sayce, and S. Harbell, editors. Spartina workshop record. Washington Sea Grant Program, University of Washington, Seattle, Washington, USA.

Larsen, E. M., and S. A. Richardson. 1990. Some effects of a major oil spill on wintering shorebirds at Grays Harbor, Washington. Northwestern Naturalist 71:88-92.

Laska, S. 1997. A comprehensive waste management model for marine debris. Pages 203-211 *in* Coe, J. M. and D. B. Rogers, editors. Marine debris: sources, impacts, and solutions. Springer-Verlag, New York.

Laubhan, M. K., and L. H. Fredrickson. 1993. Integrated wetland management: concepts and opportunities. Transactions of North American Wildlife and Natural Resources Conference 58:323-334.

Lavers, C., and R. Haines-Young. 1997. The use of satellite imagery to estimate dunlin *Calidris alpina* abundance in Caithness and Sutherland and in the Shetland Islands. Bird Study 44:220-226.

Lee, J. M. 1978. Effects of transmission lines on bird flights: studies of Bonneville Power Administration lines. Pages 93-116 *in* M. L. Avery, editor. Impacts of transmission lines on birds in flight: proceedings of a workshop. U.S. Fish and Wildlife Service, FWS/OBS 78-48. Washington, D.C.

Leighton, F. A. 1990. The toxicity of petroleum oil to birds: an overview. Pages 43-57 *in* J. White, L. Frank, T. Williams, and R. Davis, editors. The effects of oil on wildlife. The Sheridan Press, Hanover, Pennsylvania, USA.

Lester, R. T., and J. P. Myers. 1989-90. Global warming, climate disruption, and biological diversity. Pages 177-221 *in* W. J. Chandler, editor. Audubon Wildlife Report, Academic Press, San Diego, California, USA.

Liffmann, M. and L. Boogaerts. 1997. Linkages between land-based sources of pollution and marine debris. Pages 359-366 *in* Coe, J. M. and D. B. Rogers, editors. Marine debris: sources, impacts, and solutions. Springer-Verlag, New York.

Liffmann, M., B. Howard, K. O'Hara, and J. M. Coe. 1997. Strategies to reduce, control, and minimize land-source marine debris. Pages 381-390 *in* Coe, J. M. and D. B. Rogers, editors. Marine debris: sources, impacts, and solutions. Springer-Verlag, New York.

Maccarone, A. D. and J. N. Brzorad. 1995. Effects of an oil spill on the prey populations and foraging behavior of breeding wading birds. Wetlands 15:397-407.

Madsen, J. and A. D. Fox. 1995. Impacts of hunting disturbance on waterbirds - a review. Wildlife Biology 1:193-207.

Martin, A. P. And R. M. Randall. 1987. Number of waterbirds at a commercial saltpan, and suggestions for management. South African Journal of Wildlife Research 17:73-81.

Martin-Löf, P. 1961. Mortality rate calculations on ringed birds with special reference to the dunlin (*Calidris alpina*). Arkiv För Zoologi 13:483-491.

Meltofte, H., J. Blew, J. Frikke, H. U. Rösner, and C. Smit. 1994. Numbers and distribution of waterbirds in the Wadden Sea. IWRB special publication 34, IWRB, Slimbridge, United Kingdom.

Metcalfe, N. B. 1984. The effects of habitat on the vigilance of shorebirds: is visibility important? Animal Behaviour 32:981-985.

Millard, A. V., and P. R. Evans. 1984. Colonization of mudflats by *Spartina anglica*: some effects on invertebrate and shorebird populations at Lindisfame. Pages 41-48 *in* P. Doody, editor. Spartina anglica in Great Britain. Nature Conservancy Council, Peterborough, United Kingdom.

Mono Basin Ecosystem Study Committee. 1987. The Mono Basin ecosystem: effects of changing lake level. National Academic Press, Washington, D.C., USA.

Morrison, R. I. G. 1984. Migration systems of some New World shorebirds. Pages 125-202 *in* J. Burger and B. L. Olla, editors. Behavior of marine mammals, Volume 5. Shorebirds: breeding behavior and populations. Plenum Press, New York, New York, USA.

))))). 1991. Research requirements for shorebird conservation. Transactions of the North American Wildlife and Natural Resources Conference 56:473-480.

))))), A. Bourget, R. Butler, H. L. Dickson, C. Gratto-Trevor, P. Hicklin, C. Hyslop, and R. K. Ross. 1994b. A preliminary assessment of the status of shorebird populations in Canada. Canadian Wildlife Service Program Notes, Number 208.

))))), and N. C. Davidson. 1989. Migration, body condition and behaviour of shorebirds at Alert, Ellesmere Island, NWT. Syllogeus (National Museum Natural History), Ottawa, Ontario, Canada.

))))), C. Downes, and B. Collins. 1994a. Population trends of shorebirds on fall migration in eastern Canada. Wilson Bulletin 106:431-447.

Moser, M. E. 1987. A revision of population estimates for waders (Charadrii) wintering on the coastline of Britain. Biological Conservation 39:153-164.

))))). 1988. Limits to the numbers of grey plovers *Pluvialis squatarola* wintering on British estuaries: an analysis of long-term population trends. Journal of Applied Ecology 25:473-485.

Mumford, T. F., Jr., P. Peyton, J. R. Sayce, and S. Harbell, editors. 1991. *Spartina* workshop record. Washington Sea Grant Program, University of Washington, Seattle, Washington, USA.

Musters, C. J. M., M. A. W. Noordervliet, and W. J. ter Keurs. 1995. Bird casualties and wind turbines near the Kreekrak sluices of Zeeland. Milieu-biologie R.U. Leiden, Leiden, Netherlands.

))))), ))))), ))))). 1996. Bird casualties caused by a wind energy project in an estuary. Bird Study 43: 124-126.

Myers, J. P. 1983. Conservation of migrating shorebirds: staging areas, geographic bottlenecks, and regional movements. American Birds 37:23-25.

))))). 1988-89. The Sanderling. Pages 651-666 *in* W. J. Chandler, editor. Audubon wildlife report 1988/1989. Academic Press, San Diego, California, USA.

))))), C. T. Schick, and G. Castro. 1986. Structure in sanderling (*Calidris alba*) populations: the magnitude of intra- and interyear dispersal during the non-breeding season. Proceedings of the International Ornithological Congress 19:604-614.

))))), P. D. McLain, R. I. G. Morrison, P. Z. Antas, P. Canevari, B. A. Harrington, T. E. Lovejoy, V. Pulido, M. Sallaberry, and S. E. Senner. 1987a. The Western Hemisphere Shorebird Reserve Network. Wader Study Group Bulletin 49 (Supplemental): 122-124.

))))), R. I. G. Morrison, P. Z. Antas, B. A. Harrington, T. E. Lovejoy, M. Sallaberry, S. E. Senner, and A. Tarak. 1987b. Conservation strategy for migratory species. American Scientist 75:19-26.

Neel, L. A. and W. G. Henry. 1996. Shorebirds of the Lahontan Valley, Nevada, USA: a case history of western Great Basin Shorebirds. International Wader Studies 9:15-19.

Nehls, G., and R. Tiedemann. 1993. What determines the densities of feeding birds on tidal flats? A case study on dunlin, *Calidris alpina*, in the Wadden Sea. Netherlands Journal of Sea Research 31:375-384.

Nichols, F. H., J. K. Thompson, and L. E. Schemel. 1990. Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam *Potamo-corbula amurensis*. II. Displacement of a former community. Marine Ecology Progress Series 66:95-101.

Nilsson, L. 1997. Restoring inland shore-meadows for breeding birds. Wader Study Group Bulletin 84:39-44.

Ninaber, E. 1997. MARPOL Annex V, commercial ships, and port reception facilities: making it work. Pages 239-243 *in* Coe, J. M. and D. B. Rogers, editors. Marine debris: sources, impacts, and solutions. Springer-Verlag, New York.

Nysewander, D. R. 1977. Reproductive success of the black oystercatcher in Washington state. Thesis, University of Washington, Seattle, Washington, USA.

Odum, E. P. 1987. Reduced-input agriculture reduces nonpoint pollution. Journal of Soil and Water Conservation 42:412-413.

Ohlendorf, H. M., D. J. Hoffman, M. K. Saiki, and T. W. Aldrich. 1986. Embryonic mortality and abnormalities of aquatic birds: apparent impacts of selenium from irrigation drainwater. Science of the Total Environment 52:49-63.

Oring, L. W., E. M. Gray, and J. M. Reed. 1997. Spotted sandpiper (*Actitus macularia*). Pages 1-32 *in* A. Poole, and F. Gill, editors. The birds of North America, Number 289. The Academy of Natural Sciences, Philadelphia, Pennsylvania, and The American Ornithologists' Union, Washington, D.C., USA.

Page, G., B. Pearls, and R. M. Jurek. 1972. Age and sex composition of western sandpipers on Bolinas Lagoon. Western Birds 3:79-86.

Page, G. W., L. E. Stenzel, and C. M. Wolfe. 1979. Aspects of the occurrence of shorebirds on a central California estuary. Studies in Avian Biology 2: 15-32.

))))), and R. E. Gill, Jr. 1994. Shorebirds in western North America: late 1800s to late 1900s. Studies in Avian Biology 15:147-160.

))))), and D. F. Whitacre. 1975. Raptor predation on wintering shorebirds. Condor 77:73-83.

Parsons, K. C. 1996. Recovering from oil spills: the role of proactive science in mitigating adverse effects. Colonial Waterbirds 19:149-153.

Paton, P. W. C., and V. C. Bachman. 1996. Impoundment drawdown and artificial nest structures as management strategies for snowy plovers. International Wader Studies 9:64-70.

Paulson, D. R. 1992. Northwest bird diversity: from extravagant past and changing present to precarious future. Northwest Environmental Journal 8:71-l18.

))))). 1993. Shorebirds of the Pacific Northwest. University of Washington Press, Seattle, Washington, USA.

Payne, N. J., B. V. Helson, K-M. S. Sundaram, and R. A. Fleming. 1988. Estimating buffer zone widths for pesticide applications. Pesticide Science 24:147-161.

Perkins, G. A. and J. S. Lawrence. 1985. Bird use of wetlands created by surface mining. Transactions of the Illinois State Academy of Science 78:87-96.

Pfister, C., B. A. Harrington, and M. Lavine. 1992. The impact of human disturbance on shorebirds at a migration staging area. Biological Conservation 60:115-126.

Phipps, J. B. 1990. Coastal accretion and erosion in southwest Washington: 1977-1987. Shorelands and Coastal Zone Management Program, Washington Department of Ecology, Olympia, Washington, USA.

Pienkowski, M. W. 1981. How foraging plovers cope with environmental effects on invertebrate behavior and availability. Pages 179-192 *in* N. V. Jones and W. J. Wolff, editors. Feeding and survival strategies of estuarine organisms. Plenum Press, New York, New York, USA.

Powers, L. C. and H. A. Glimp. 1996. Impacts of livestock on shorebirds: a review and application to shorebirds of the western Great Basin. International Wader Studies 9:55-63.

Prater, A. J. 1981. Estuary birds of Britain and Ireland. Poyser, Calton, United Kingdom.

Quammen, M. L. 1982. Influence of subtle substrate differences on feeding by shorebirds on intertidal mudflats. Marine Biology 71:339-343.

Ratti, J. T., and J. A. Kadlec. 1992. Concept plan for the preservation of wetland habitat of the Intermountain West. U.S. Fish and Wildlife Service, Portland, Oregon, USA.

Raevel, P., and J. C. Tombal. 1991. Impact des lignes hautetension sur l'avi faune. Vol. 2. Les Cahiers de L'A.M.B.E. et Environnement.

Redmond, R. L. and D. A. Jenni. 1986. Population ecology of the long-billed curlew (*Numenius americanus*) in western Idaho. Auk 103:755-767.

Rehfisch, M. M. 1994. Man-made lagoons and how their attractiveness to waders might be increased by manipulating the biomass of an insect benthos. Journal of Applied Ecology 31:383-401.

))))), N. A. Clark, R. H. W. Langston, and J. J. D. Greenwood. 1996. A guide to the provision of refuges for waders: an analysis of 30 years of ringing data from the Wash, England. Journal of Applied Ecology 33:673-687.

Reid, F. A., W. D. Rundle, M. W. Sayre, and P. R. Covington. 1983. Shorebird migration chronology at two Mississippi River Valley wetlands of Missouri. Transactions of the Missouri Academy of Science 17:103-115.

Reise, K. 1985. Tidal flat ecology. Springer-Verlag, Berlin, Germany.

Redford, D. P., H. K. Trulli, and W. R. Trulli. 1997. Sources of plastic pellets in the aquatic environment. Pages 335-343 *in* Coe, J. M. and D. B. Rogers, editors. Marine debris: sources, impacts, and solutions. Springer-Verlag, New York.

Ribic, C. A., S. W. Johnson, and C. A. Cole. 1997. Distribution, type, accumulation, and source of marine debris in the United States, 1989-1993. Pages 35-47 *in* Coe, J. M. and D. B. Rogers, editors. Marine debris: sources, impacts, and solutions. Springer-Verlag, New York.

Robards, M. D., P. J. Gould, and J. F. Piatt. 1997. The highest global concentrations and increased abundance of oceanic plastic debris in the North Pacific: evidence from seabirds. Pages 71-80 *in* Coe, J. M. and D. B. Rogers, editors. Marine debris: sources, impacts, and solutions. Springer-Verlag, New York.

Robel, R. J. 1961. The effects of carp populations on the production of waterfowl food plants on a western waterfowl marsh. Transactions of the North American Wildlife and Natural Resources Conference 26:147-159.

Roberts, G., and P.R. Evans. 1993. Responses of foraging sanderlings to human approaches. Behaviour 126:29-43.

Robinson, J. A., and S. E. Warnock. 1996. The staging paradigm and wetland conservation in arid environments: shorebirds and wetlands of the North American Great Basin. International Wader Studies 9:37-44.

Roemmich, D., and J. A. McGowan. 1995. Climatic warming and the decline of zooplankton in the California Current. Science 267:1324-1326.

Rohwer, S., D. F. Martin, and G. G. Benson. 1979. Breeding of the black-necked stilt in Washington. Murrelet 60:67-71.

Rönkä, A., and K. Koivula. 1997. Effect of shore width on the predation rate of artificial wader nests. Ibis 139:405-407.

Rottenborn, S. C. 1996. The use of coastal agricultural fields in Virginia as foraging habitat by shorebirds. Wilson Bulletin 108:783-796.

Rubega, M. A. and J. A. Robinson. 1996. Water salinization and shorebirds: emerging issues. International Wader Studies 9:45-54.

Ruggiero, L. F., K. B. Aubry, R. S. Holthausen, J. W. Thomas, B. G. Marcot, and E. C. Meslow. 1988. Ecological dependency: the concept and its implications for research and management. Transactions of the North American Wildlife and Natural Resources Conference 53:115-126.

Rundle, W. D. and L. H. Fredrickson. 1981. Managing seasonally flooded impoundments for migrant rails and shorebirds. Wildlife Society Bulletin 9:80-87.

Ryan, P. G. 1988. Effects of ingested plastic on seabird feeding: evidence from chickens. Marine Pollution Bulletin 19:125-128.

Saiki, M. K. and T. P. Lowe. 1987. Selenium in aquatic organisms from subsurface agricultural drainage water, San Joaquin Valley, California. Archives of Environmental Contamination and Toxicology 16: 657-670.

Sampath, K., and K. Krishnamurthy. 1988. Shorebirds of the salt ponds at the Great Vedaranyam salt swamp-Tamil Nedu, India. Stilt 15:20-23.

Sauer, J. R., J. E. Lines, G. Gogh, I. Thomas, and B.G. Peterjohn. 1997. The North American Breeding Bird Survey: results and analysis. Version 96.3. Patuxent Wildlife Research Center, Laurel, MD. [data from <www.patuxent> web site]

Sayce, K. 1988. Introduced cordgrass, *Spartina alterniflora* Loisel, in salt marshes and tidelands of Willapa Bay, Washington. U.S. Fish and Wildlife Service.

Schick, C. T., L. A. Brennan, J. B. Buchanan, M. A. Finger, T. M. Johnson, and S. G. Herman. 1987. Organochlorine contamination in shorebirds from Washington state and the significance for their falcon predators. Environmental Monitoring and Assessment 8:1-17.

Schmidt-Nielsen, K. 1960. The salt-secreting gland of marine birds. Circulation 21:955-967.

Schneider, D. C. and B. A. Harrington. 1981. Timing of shorebird migration in relation to prey depletion. Auk 98:801-811.

Scott, R. E., L. J. Roberts, and C. J. Cadbury. 1972. Bird deaths from powerlines at Dungeness. British Birds 65:273-286.

Seelye, J. G., R. J. Hesselberg, and M. J. Mac. 1982. Accumulation by fish of contaminants released from dredged sediments. Environmental Science and Technology 16:459-464.

Senner, S. and M. A. Howe. 1984. Conservation of nearctic shorebirds. Pages 379-421 *in* J. Burger and B. L. Olla, editors. Behavior of marine mammals, Volume 5. Shorebirds: breeding behavior and populations. Plenum Press, New York, New York, USA.

Sileo, L., L. Karstad, R. Frank, M. V. H. Holdrinet, E. Addison, and H. E. Braun. 1977. Organochlorine poisoning of ring-billed gulls in southern Ontario. Journal of Wildlife Diseases 13:313-322.

Simenstad, C. A., J. R. Cordell, and L. A. Weitkamp. 1991. Effects of substrate modification on littoral flat meiofauna: assemblage structure changes associated with adding gravel. Contract report FRI-UW-9111 to Washington Department of Fisheries, Brinnon, Washington, USA.

Skagen, S. K. 1997. Stopover ecology of transitory populations: the case of migrant shorebirds. Ecological Studies 125:244-269.

)))))). and F. L. Knopf. 1994. Migrating shorebirds and habitat dynamics at a prairie wetland complex. Wilson Bulletin 106:91-105.

Smit, C. J., R. H. D. Lambeck, and W. J. Wolff. 1987. Threats to coastal wintering and staging areas of waders. Wader Study Group Bulletin 49 (Supplemental):105-113.

))))), and G. J. M. Visser. 1993. Effects of disturbance on shorebirds: a summary of existing knowledge from the Dutch Wadden Sea and Delta area. Wader Study Group Bulletin 68 (special issue):6-19.

Smith, K. G., J. C. Neal, and M. A. Mlodinow. 1991. Shorebird migration at artificial fish ponds in the prairie-forest ecotone of northwestern Arkansas. Southwestern Naturalist 36:107-113.

Smith, P. C. and J. S. Bleakney. 1969. Observations on oil pollution and wintering purple sandpipers, *Erolia maritima* (Brunnich), in Nova Scotia. Canadian Field-Naturalist 83:19-22.

Soikkeli, M. 1967. Breeding cycle and population dynamics in the dunlin (*Calidris alpina*). Annales Zoologici Fennici 4:158-198.

Strauch, J. G., Jr. 1966. Spring migration of dunlin in interior western Oregon. Condor 68:210-212.

Stone, K. L. 1994. Shorebird habitat use and responses to burned marshes during spring migration in south-central Kansas. Thesis, Oklahoma State University, Stillwater, Oklahoma, USA.

Streeter, R. G., M. W. Tome, and D. K. Weaver. 1993. North American waterfowl management plan: shorebird benefits? Transactions of the North American Wildlife and Natural Resources Conference 58:363-369.

Sutherland, W. J. and J. D. Goss-Custard. 1991. Predicting the consequence of habitat loss on shorebird populations. Proceedings of the International Ornithological Congress 20:2199-2207.

Sutinen, J. G. 1997. A socioeconomic theory for controlling marine debris: is moral suasion a reliable policy tool? Pages 161-170 *in* Coe, J. M. and D. B. Rogers, editors. Marine debris: sources, impacts, and solutions. Springer-Verlag, New York.

Symonds, F. L., D. R. Langslow, and M. W. Pienkowski. 1984. Movements of wintering shorebirds within the Firth of Forth: species differences in usage of an intertidal complex. Biological Conservation 28:187-215.

Taylor, D. M., C. H. Trost, and B. Jamison. 1993. Migrant shorebird habitat use and the influence of water level at American Falls Reservoir, Idaho. Northwestern Naturalist 74:33-40.

Townshend, D. J. 1981. The importance of field feeding to the survival of wintering male and female curlews *Numenius arquata* on the Tees estuary. Pages 261-273 in N. V. Jones and W. J. Wolff, editors. Feeding and survival strategies of estuarine organisms. Plenum Press, New York, New York, USA.

))))). 1984. The effects of predators upon shorebird populations in the nonbreeding season. Wader Study Group Bulletin 40:51-54.

))))). 1985. Decisions for a lifetime: establishment of spatial defense and movement patterns by juvenile grey plovers (*Pluvialis squatarola*). Journal of Animal Ecology 54:267-274.

van der Have, T. and E. Nieboer. 1984. Age-related distribution of dunlin in the Dutch Wadden Sea. Pages 160-176 *in* Evans, P. R., J. D. Goss-Custard, and W. G. Hale, editors. Coastal waders and wildfowl in winter. Cambridge University Press, Cambridge, Massachusetts, USA.

van Impe, J. 1985. Estuarine pollution as a probable cause of increase of estuarine birds. Marine Pollution Bulletin 16:271-276.

Veit, R. R., P. Pyle, and J. A. McGowan. 1996. Ocean warming and long-term change in pelagic bird abundance within the California current system. Marine Ecology Progress Series 139:11-18.

Velasquez, C. R. and P. A. R. Hockey. 1992. The importance of supratidal foraging habitats for waders at a south temperate estuary. Ardea 80:243-253.

Vermeer, K., R. W. Butler, and K. H. Morgan. 1994. Comparison of seasonal shorebird and waterfowl densities within Fraser River delta intertidal regions. Pages 6-17 *in* R. W. Butler and K. Vermeer, editors. The abundance and distribution of estuarine birds in the Strait of Georgia, British Columbia. Canadian Wildlife Service Occasional Paper, Number 83.

))))), K. H. Morgan, and G. E. J. Smith. 1989. Population and nesting habitat of American black oystercatcher in the Strait of Georgia. Pages 118-122 *in* K. Vermeer and R. W. Butler, editors. The ecology and status of marine and shoreline birds in the Strait of Georgia, British Columbia. Special Publication, Canadian Wildlife Service.

))))), and R. Verneer. 1975. Oil threat to birds on the Canadian west coast. Canadian Field-Naturalist 89: 278-298.

Wahl, T. R. 1995. Birds of Whatcom County: status and distribution. Independently published. Bellingham, Washington, USA.

Wallace, B. 1997. A strategy to reduce, control, and minimize vessel-source marine debris. Pages 277-286 *in* Coe, J. M. and D. B. Rogers, editors. Marine debris: sources, impacts, and solutions. Springer-Verlag, New York.

Wanink, J. H. and L. Zwarts. 1993. Environmental effects on the growth rate of intertidal invertebrates and some implications for foraging waders. Netherlands Journal of Sea Research 31:407-418.

Warnock, N. 1996. Local and regional differences in habitat utilization by dunlins *Calidris alpina* as revealed by radio-telemetry: conservation implications. International Wader Studies 8:35-38.

))))), G. W. Page, and B. K. Sandercock. 1997. Local survival of dunlin wintering in California. Condor 99:906-915.

)))) , )))), )))), and L. E. Stenzel. 1995. Non-migratory movements of dunlins on their California wintering grounds. Wilson Bulletin 107:131-139.

)))), and S. E. Schwarzbach. 1995. Incidental kill of dunlin and killdeer by strychnine. Journal of Wildlife Diseases 31:566-569.

Warnock, S. E., and J. Y. Takekawa. 1995. Habitat preferences of wintering shorebirds in a temporally changing environment: western sandpipers in the San Francisco Bay estuary. Auk 112:920-930.

Washington Department of Agriculture, Washington Department of Ecology, Washington Department of Natural Resources, Washington Department of Fisheries, Washington Department of Wildlife, and Noxious Weed Control Board. 1993. Noxious emergent plant management. Final environmental impact statement, Olympia, Washington, USA.

Washington Department of Fish and Wildlife. 1995a. Washington state recovery plan for the snowy plover. Washington Department of Fish and Wildlife, Olympia, Washington, USA.

))))). 1995b. Washington state recovery plan for the upland sandpiper. Washington Department of Fish and Wildlife, Olympia Washington, USA.

))))). 1995c. Integrated weed management plan for *Spartina* control on Washington Department of Fish and Wildlife lands in Willapa Bay. Washington Department of Fish and Wildlife, Olympia Washington, USA.

Weber, L. M. and S. M. Haig. 1996. Shorebird use of South Carolina managed and natural coastal wetlands. Journal of Wildlife Management 60:73-82.

Weston, M. A. 1997. Disturbance of common sandpipers *Actitus hypoleucos* by motorboats. Stilt 30:50-51.

White, D. H., K. A. King, and R. M. Prado. 1980. Significance of organochlorine and heavy metal residues in wintering shorebirds at Corpus Christi, Texas, 1976-77. Pesticides Monitoring Journal 14: 58-63.

White, D. H., C. A. Mitchell, and T. E. Kaiser. 1983. Temporal accumulation of organochlorine pesticides in shorebirds wintering on the south Texas coast. Archives of Environmental Contamination and Toxicology 12:241-245.

Whitfield, D. P., A. D. Evans, and P. A. Whitfield. 1988. The impact of raptor predation on wintering waders. Proceedings of International Ornithological Congress 19:674 -687.

Wilcox, C. G. 1986. Shorebird and waterfowl use on restored and natural intertidal wetlands at Upper Newport Bay, California. Colonial Waterbirds 9: 218-226.

Williams, M. L., R. L. Hothem, and H. M. Ohlendorf. 1989. Recruitment failure in American avocets and black-necked stilts nesting at Kesterson Reservoir, California, 1984-1985. Condor 91:797-802.

Wolheim, W. M., and J. R. Lovvorn. 1995. Salinity effects on macroinvertebrate assemblages and waterbird food webs in shallow lakes of the Wyoming High Plains. Hydrobiologia 310:207-223.

Yates, M. G., A. R. Jones, J. D. Goss-Custard, and S. McGrorty. 1993a. Satellite imagery to monitor ecological change in estuarine systems: example of the Wash, England. Pages 56-60 *in* M. Moser, R. C. Prentice, and J. van Vessem, editors. Waterfowl and wetland conservation in the 1990s: a global perspective. International Waterfowl and Wetlands Research Bureau, Special Publication Number 26. United Kingdom.

))))), ))))), S. McGrorty, and J. D. Goss-Custard. 1993b. The use of satellite imagery to determine the distribution of intertidal surface sediments of the Wash, England. Estuarine, Coastal and Shelf Science 36:333-344.

Zinkl, J. G., D. A. Jessup, A. I. Bischoff, T. E. Lew, and E. B. Wheeldon. 1981. Fenthion poisoning of wading birds. Journal of Wildlife Diseases 17:117-119.

Zwarts, L. and J. H. Wanink. 1993. How the food supply harvestable by waders in the Wadden Sea depends on the variation in energy density, body weight, biomass, burying depth and behavior of tidal-flat invertebrates. Netherlands Journal of Sea Research 31:441-476.

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## KEY POINTS

### Habitat Requirements

*Coastal Environments*

- The primary habitat requirements of migrant or winter resident shorebirds relate to the availability of adequate foraging and roosting areas.

- Most species in western Washington are associated with silt or silt/sand intertidal areas and adjacent beaches or salt marshes. Pastures and agricultural land are also used by roosting and foraging shorebirds in western Washington.

- Shorebirds are adapted to forage in a narrow range of microhabitat conditions, from exposed tide flats or beaches to shallow water, salt marshes, and even open water.

- The foraging requirements of many shorebirds are met primarily in estuarine ecosystems, where tidal mud flats provide foraging substrates. Black-bellied plover, dunlin, western sandpiper, and dowitchers forage on mud flats with high levels of silt, whereas semipalmated plovers and sanderlings forage in sandy or silt/sand areas. Other species, such as rock sandpiper, surfbird, and wandering tattler are found almost exclusively along rocky intertidal shores.

- Shorebirds often roost in salt marshes adjacent to intertidal feeding areas, but will use a variety of habitats. Shorebirds at Grays Harbor and Willapa Bay often roost in large flocks on Pacific beaches, occasionally concentrating near the mouths of small creeks. In some areas, shorebirds roost on naturally-occurring and dredge-spoil islands and on higher elevation sand beaches. Some species may also roost in fields near intertidal foraging areas; foraging occurs at these or other roost sites if suitable prey are present. Shorebirds occasionally roost on log rafts, floating docks, and other floating structures when natural roost sites are limited.

- Use of artificial wetlands by shorebirds has not been documented in Washington. However, many species of shorebirds, including at least 12 species that occur in western Washington, use artificial or managed coastal wetlands in other parts of the United States and the world. Artificial wetlands could potentially provide important shorebird habitat in Washington.

- Shorebirds are generally site-faithful to specific wintering areas. This fidelity to particular sites has important ramifications for conservation management and mitigation.

*Freshwater Environments*

- Many species in eastern Washington use wet meadows, flooded fields and other areas of shallow water.

- Most shorebirds that forage in freshwater areas require ponds and pools that have exposed shorelines or that are shallow enough to allow foraging by wading birds. As with estuarine sites, the availability of appropriate invertebrate prey and roost sites are important habitat requirements.

- Habitats used by shorebirds in nonestuarine regions include marshes, pastures, flooded fields, reservoirs, impoundment drawdowns, stormwater wetlands, and other artificial wetlands.

## Management Recommendations

*Habitat Protection*

- Identify and preserve wetland habitats important to shorebirds. Assemblages of smaller sites, as well as major estuaries provide critical habitat to shorebirds in Washington.

- Where livestock grazing occurs in pastures used by shorebirds, assess for potential trampling or disturbance of nesting birds.

- Assess commercial sand and gravel extraction from beach and riverine areas for potential impacts to shorebirds. The development of a review process for these activities would help ensure that shorebirds are considered as part of the permitting process.

- Avoid placement of new utility towers and lines in flight corridors or near wetland areas used by shorebirds. New lines should be placed below ground if possible.

- Where possible, treat existing utility lines to make them more detectable by birds in areas where collisions with shorebirds have occurred or are likely to occur. Techniques include coating or painting wires, marking of wires with mobile spirals or strips of fiberglass or plastic, placement of predator silhouettes, warning lights, and acoustical devices to scare birds. Static wire-marking may effectively reduce the number of collisions with power lines. Grouping multiple lines may make them more visible to birds and will occupy a smaller area of flight space. In addition, it is suggested that the lines be arranged side by side rather than in a vertical stacked formation.

- Address shorebirds and their flight corridors in wind turbine and cellular tower proposals.

- In the event of an oil spill, limit public access to beach or estuarine spill sites. The impacts of an oil spill can be exacerbated by disturbances caused by human recreation (e.g., beach walking).

- Control the entry of plastic litter into the marine environment. Small plastic particles injure surface feeding marine birds that inadvertently ingest them.

- Continue efforts to control the establishment and growth of cordgrass, purple loosestrife, and other noxious weeds. Potential methods to eradicate noxious weeds include biological control, repeated mowing, hand pulling of seedlings, and chemical treatment.

- Use extreme caution when applying chemicals near habitats used by shorebirds. Encourage alternatives to chemical use. Appendix A (of this volume) lists contacts useful in assessing pesticides, herbicides, and their alternatives.

- Use current information to establish buffer zones when applying chemicals. Implement buffer zones around shorebird and waterfowl nesting habitat in agricultural landscapes to minimize the impacts of spray drift.

- Assess whether or not public access and human activities should be controlled at areas important to shorebirds. If needed, potential solutions may include erecting cordons to restrict foot traffic from roosting or foraging sites, and establishing vehicle restriction zones during critical roosting periods.

*Restoration/Creation of Habitat*

- Develop a site-specific strategy for any restoration project affecting shorebirds. Information on local water, soil, and vegetation conditions and requirements (freshwater environments) or tidal, wind pattern, sea swell, and substrate conditions (marine environments) needs to be incorporated.

- Create new sites at least five years prior to modification of natural habitat. Artificially created sites should provide for all displaced birds and should address this need at least 5 years prior to the modification of natural habitat to allow an assessment of its success. This 5-year period is needed to 1) identify suitable sites; 2) acquire, design, and construct the mitigation features at sites; 3) allow settlement and stabilization of suitable sediments; and 4) allow colonization of sufficient densities of invertebrate prey species.

- When conducting mitigation studies, model population dynamics in a variety of local habitats over wide spatial (e.g. coastal, Puget Sound, and interior) and temporal (e.g., at least 5 years) scales.

- Evaluate shorebird use of artificial impoundments. Artificially-created sites may be very important to shorebirds, particularly in the Columbia Basin. Artificial drawdown sites may provide more nesting opportunities for certain species depending on the type of shoreline or the availability of nesting substrate. In addition, efforts to modify such sites should be evaluated in the same manner as undisturbed sites.

- Create adequate roost sites. A primary consideration in creating a roost site is that it must be designed to address the needs of the species that will use the site. Island roosts should provide shelter from strong winds or sea swell if these are significant environmental conditions in the particular area. Island roosts should also be open, with flat tops and gently sloping sides so that the birds can effectively scan for predators.

- Manage artificial (freshwater) sites for breeding season use as well as fall migration.

- Maximize invertebrate production at artificial (freshwater) sites.

- Maintain agricultural areas and pasturelands near sites used by shorebirds.

- Practical considerations regarding management of artificial sites include:
  - proper design and use of spillways in areas prone to flooding and erosion,
  - control of exotic species such as carp and purple loosestrife,
  - water flow maintenance that minimizes stagnant water and reduces the likelihood of outbreaks of avian cholera and botulism Type C,
  - an assessment of soil conditions to determine whether a site will effectively hold water (e.g., prevention of drainage to the water table, or seepage through dikes).

*Policy needs and considerations for government agencies and conservation organizations*

- Initiate and design conservation planning efforts to address the following:
  - comprehensive, multi-species, landscape-level or ecosystem plans that address many species, habitats, as well as factors such as community dynamics.
  - flyway-level biological and policy coordination among states and provinces to improve regional management and enhance opportunities to protect shorebird populations.

- Identify important local and regional sites.

- Preserve remaining wetland habitat. Locally or regionally important sites should be purchased to reduce the risk of loss or degradation of habitat important for shorebirds and other wildlife. New protective and regulatory legislation needs development, and existing laws concerning wetland use need more effective enforcement.

- Promote public education about chemical use and wetland functions. Implementation of an integrated training and certification program for landowners and commercial pesticide applicators has been recommended as a means to provide pesticide users with important biological information and training.

- Continue the development and refinement of oil trajectory models.

- Develop site-specific strategies to manage human disturbance. Potential strategies include developing informational signs that identify or describe important foraging or roosting areas and organizing groups of volunteers ("beach patrols") to educate the public about shorebird ecology.

- Post informational signs at boat docks, moorage areas, and beach access points to explain the impacts of disturbances caused by boats, personal watercraft, unleashed dogs, and other human activities.

- Address the effects of human disturbance in refuge management plans. Refuges should be designed to provide disturbance-free areas and should take into account the ecology of the species expected to use the area.

- Assess the level of unintentional mortality due to hunting. An evaluation of this source of mortality would provide an indication as to whether a new identification/information guide for shorebirds should be developed for inclusion in a waterfowl hunting pamphlet.

- Implement educational programs to inform the public about the ecology and behavior of shorebirds. Public education programs should emphasize the regional and international scope of shorebird conservation. Such efforts require improved information on the basic ecology of flyway species, identification of significant threats or potential impacts, and development of real conservation measures.

- Undertake comprehensive efforts to control the spread of exotic invertebrates in marine waters.